FLOOD PLAIN CRITERIA AND MANAGEMENT EVALUATION STUDY

prepared by:
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for:
ONTARIO MINISTRY OF NATURAL RESOURCES
ONTARIO MINISTRY OF HOUSING

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13 December 1976

Mr. A. D. Latornell
Chairman
Flood Plain Criteria Steering Committee
Whitney Block
Queen's Park
Toronto, Ontario

Dear Mr. Latornell:

It is with great pleasure that we submit to you our report on the Flood Plain Criteria and Management Evaluation Study.

This summary report is one of five volumes which together contain the research and reference material relevant to the study. The other four volumes include the background material on engineering, planning and economic aspects.

The subject of flood plain regulations and in particular the design criteria on which these regulations are based is of vital concern to Provincial, Municipal and Conservation Authorities officials. Although, as requested in the Terms of Reference the study report does not make recommendations, it is hoped that it provides the necessary background material to formulate criteria which will be acceptable to all concerned.

Yours truly,

M. M. DILLON LIMITED

F.I. Lorant, P.Eng.
Project Manager

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ACKNOWLEDGMENTS

We acknowledge with gratitude the co-operation and assistance of the Steering Committee which was comprised as follows:

A.D. Latornell, P.Eng., Chairman of the Steering Committee, Ministry of Natural Resources

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Background

The main objectives of current provincial flood plain management policy are to prevent loss of life and to minimize flood damage to existing and proposed flood plain development. The current criteria for establishing flood plain objectives regarding the use of undeveloped flood plain lands are frequently challenged, particularly in view of recent accelerating land values.

A review of present policies was undertaken for the Ministry of Natural Resources and the Ministry of Housing to assist the Ministry staff in their evaluation of flood plain management practices. The following report is limited to conceptual statements as required by the Terms of Reference and does not contain recommendations.

The magnitude of flooding problems is demonstrated by the fact that in the 20 year period of 1950-1970, 430 floods occurred in Ontario. Hurricane Hazel, in 1954, caused over $75 million in damage and significant loss of life. A more recent flood in the Grand River watershed in 1974 caused $7 million damages, not including business losses.

The key method for determining the extent of the flood plain is the use of flood lines established by studying special floods called Regional Floods. In the past, appropriate Regional flood lines were based on Regional Storms defined as Hurricane Hazel, The Timmins Storm, or the 1 in 100-year flood, depending on geographical location.

Evaluation of Current Policies

The uncontrolled urban development in the flood plain preceding the 1950s has been gradually reversed. A major role in this trend was played by conservation authorities, that invested in excess of $60 million between 1950 and 1970 through their flood plain management programs. Also during the 1960s land use planning matured and many municipalities began to incorporate watershed management considerations into the development of Official Plans.

Watersheds undergoing development, portions of which may lie within the Regional flood line, require investigation of flood control alternatives to be used for flood plain management. Alternatives to be considered for flood damage reduction include various structural corrective methods such as dams, channel improvement, dyking, floodproofing or preventive flood plain regulations. While the corrective methods are not always feasible or require large capital investments, the preventive flood plain regulations are sometimes contrary to the existing development plans advocated by the municipalities.

Evaluation procedures used in the selection of corrective flood control alternatives are based, in most cases, on the traditional economic benefit-cost studies.

Preventive flood plain regulations generally permit no encroachment within the regulated flood plain limits. This restriction ensures that flood levels upstream or downstream are not raised due to development in the flood plain.

In most instances the Regional Flood used is far in excess of historical floods observed in the watersheds, hence the extent of flood plain is judged by some to be excessive. It must also be recognized, however, that our period of flow records is short.

In stressing an integrated flood plain management program, the regulation of flood prone lands and the possible eventual acquisition of those that are repeatedly flooded, is actively pursued to reduce property damage and forestall premature construction of structural measures. Depending upon local circumstances and watershed characteristics, various remedial works have been implemented.

The analyses of questionnaires distributed to various government agencies, municipalities and conservation authorities identified more than 70% of the respondents to be in favour of reviewing the current flood plain management policies.

Alternative Design Criteria

(A) Design Floods

1) Existing Criteria, (Regional Storms Based on Hurricane Hazel, Timmins Storm and 1 in 100-Year Flood)

The relative frequencies, hence the risk of the Hurricane Hazel and the Timmins Storm occurring in the future cannot be defined. These two Regional Storms were selected as the largest of the eight severe storms recorded in Ontario since 1900. Hazel like any tropical storm which appears in the Western Atlantic, Carribbean Sea, or Gulf of Mexico is a threat to the Province of Ontario. A comparison of total

precipitation of the two Regional Storms with the estimated 1 in 100-year precipitation indicates that Timmins is approximately 50% and Hazel is approximately 100% higher than the precipitation expected on the average once every hundred years. However, these percentages are not necessarily the same for the flows generated by the storms. The 1 in 100-year flood is used as the Regional Storm in areas such as Eastern Ontario where meteorological conditions for the occurrence of a Hurricane Hazel or Timmins type storm are not likely to be present and in larger drainage areas where the predominant flood producing event is spring runoff caused by snowmelt.

At present, approximately 6% of urban areas in Ontario lie in the flood plain - more than half of which is open space or vacant land. The value of this existing flood plain development is over $750 million.

2) More Severe Criteria

Hurricane Agnes, which struck Pennsylvania but bypassed Ontario in 1974, produced 18 inches of precipitation over a 5 day period, almost twice the Hazel values used in Ontario. Data from such a storm could be used as a basis for the application of more severe criteria.

Although these criteria would increase the amount of land classified as flood plain, they would reduce the amount of future possible flood damages.

3) Selected Flood Frequency

The use of frequency in the definition of design criteria would permit the introduction of risk factors. For example,

if a 1 in 100-year flood is chosen as the design flood, there is a 39% risk that this flood will be exceeded over the expected life of a building (50 years).

Risk in practice cannot be eliminated, it can only be reduced to an acceptable level. Even a 1000 year return period flood has a 5% risk of being equalled or exceeded in a 50 year period.

The choice of a 100-year frequency flood as a design criterion would reduce the extent of flood plain land when compared to the Hazel or Timmins criterion. To what extent the flood plain is reduced depends on the watershed characteristics but a survey of three different watersheds indicated a range of 30 - 50%.

Any reduction in the design flood criterion will increase the risk factor and decrease the amount of land classified as flood plain. However, a further reduction of the design flood from 100-year to 50-year flood will release only a marginal amount of extra land from the flood plain category but at the same time it would double the risk factor.

The Federal Government and most foreign countries surveyed use the 1 in 100-year flood as the minimum criterion. Where flood events greater than the selected design flood have been recorded, these cannot be ignored in the flood line determination, especially where loss of life could be possible.

(B) <u>Alternative Flood Plain Zoning</u>

A shift in recent times to planning and implementation of non-structural flood prevention alternatives, such as

zoning, is widespread around the world. Current zoning in Ontario recognizes only one zone; the flood plain where generally no encroachment is permitted.

The possibility of dividing the flood plain into two zones would allow the various authorities to consider a reasonable level of development activity in portions of the flood plain, using a Regional Flood criterion. This method is called the two zone concept, a variation of which has been used in Ontario by a few conservation authorities. Basically, the watercourse is divided into two zones. The central portion, called floodway, carries the flood water where all types of development are prohibited. The second zone occupies the fringes on both sides of the floodway where development is permitted by filling the flood plain or by flood-proofing. The adoption of the two zone method would not increase future flood damages if properly executed. Structural alternatives coupled with the two zone concept would provide a much wider latitude for action. Studies should be carried out to examine the economic returns together with social, aesthetic and environmental factors before selecting a design flood to be used as the criterion.

(C) <u>Alternative Policies</u>

The objectives of flood plain management policies in Ontario could be enlarged to include any or all of the following items:

(a) to prevent loss of life
(b) to alleviate damages to existing development
(c) to prevent encroachment of flood prone areas by new developments

(d) to improve land use practices in flood prone areas
(e) to create a safer and better environment
(f) to eliminate the uneconomic, hazardous, and unnecessary use of flood plains

The questionnaires identified an alternative policy based on the premise that all Official Plans include a flood plain designation and land use policies for the flood plain. Official Plans for the flood plain could be broken down into two categories: undeveloped and developed areas to reflect the differing development characteristics of municipalities throughout the Province.

For some municipalities a flexible system of flood plain land use policy may be appropriate based on special studies. These should take into account a wide range of economic, social engineering and safety factors. It is suggested for these urban municipalities, that new analysis techniques should be used to select possible alternatives. These techniques should include not only the traditional economic benefit cost studies, listing direct and indirect damages, but they should include an impact matrix approach for trade off analysis of other non-commensurable objectives such as aesthetics, recreation, open space, uncertainty and possible loss of life.

This study has identified various items related to the flood plain criteria which should be investigated. These are as follows:

There is a need to establish accepted methods for hydrologic flood prediction in Ontario. This has been endorsed by some conservation authorities, such as the Metro Toronto Region Conservation Authority. Currently used methods were developed

in the United States or in other parts of Canada. Consequently, extrapolation of these methods should be done only after their suitability has been established. This will establish in Ontario a uniform approach for hydrologic flood prediction and a more acceptable level of accuracy.

Future water management legislation should deal with all watershed related problems such as flooding, water supply, water quality, and urban and rural drainage. All related work should be co-ordinated by an inter-ministerial co-ordinating committee.

Comprehensive educational programs are urgently required to familiarize the staff of provincial, regional and local government, and conservation authorities with the evolving state of the art of flood plain management.

Conservation Authorities and local planning agencies should take a lead in informing the public on the use of flood plain land.

Flood control policies should be updated periodically to accommodate changes in society and in the technology of flood control.

1. INTRODUCTION

In the Province of Ontario the Ministry of Natural Resources has a major responsibility for policies affecting the regulation and administration of flood plain management.

The two main objectives of the policies are:

1. Alleviation of potential loss of life and damage to existing development in flood prone areas.

2. Prevention of encroachment of new developments in flood plain lands.

Currently, flood plain delineation is based upon the "regional flood" or the "1 in 100 year flood", according to the location of the watershed.

While the main objectives are generally accepted, concern has been expressed regarding the criteria used to define flood plains.

For this reason the Ministry of Natural Resources in conjunction with the Ministry of Housing decided that the present policies and standards should be reviewed. The ultimate aim of both Ministries and the Province of Ontario is the development of a stable and readily understood rationale on which to establish flood plain policies.

The firms of M. M. Dillon Limited and James F. MacLaren Limited were commissioned in March 1976 to carry out a flood plain management evaluation study. At the same time a

Steering Committee, with representatives from the two Ministries, the Conservation Authorities and an observer from the Municipal Engineers' Association, was formed to co-ordinate and supervise the project.

The Terms of Reference state that:

1) An evaluation of Flood Plain Management Policies is required by the Ontario Ministry of Natural Resources. The evaluation will provide a conceptual statement which will assist in Ministry rationalization of flood plain management practices. The report will provide sufficient and suitable information to identify benefits derived from alternative design standards.

   The Consultant's report should consist of at least the following elements:

   A) <u>A Review of the Flood Hazard</u>

      (i) examination of the history of flooding in Ontario.

      (ii) an estimate of damages resulting from the flood hazard.

   B) <u>A Summary of Current Management Practices</u>

      (i) The philosophical basis for the policies.

      (ii) an explanation of the technical consideration and their implications.

(iii) the expenditures made in flood plain management programs.

C) <u>A Comprehensive Appraisal of the Primary and Secondary Benefits of Flood Plain Management Programs</u>

(i) direct and indirect economic benefits derived from flood damage reduction programs.

(ii) secondary benefits related to the open space system in urban and urbanizing areas (recreation, sensitive areas, fish and wildlife, amenities, etc.)

D) <u>Implications of Reduction of the Design Standard General Operational Guidelines</u>

(i) the study will be applicable for making policy decisions within the context of the entire province and will recognize that not all areas have local Conservation Authorities.

(ii) the final report will be useful to the Ministry of Natural Resources and will be limited to a conceptual statement for rationalizing flood plain management programs of the Ministry.

(iii) The consultant will meet formally with the client and interested parties on a monthly basis for the duration of the project to review emerging concepts.

(iv) the consultant is free to approach representatives of other government agencies and individuals of the private sector subject to the approval of the client.

2. METHODOLOGY

The study was divided into four separate phases shown on the activity diagram at the back of the report. The first phase commenced after a thorough review of the terms of reference and included the collection and analysis of relevant data such as:

1. Land use studies to examine development patterns in Ontario with regard to flood plain (Volume D).

2. Planning, institutional, administration and legal considerations to identify the constraints related to the planning of flood plain areas (Volume D).

3. Flood plain management policies, including the state of the art in Ontario, North America and Europe (Volume A).

4. Existing hydrologic methods of predicting flood flows (Volume B).

5. The preparation of a flood plain management computer model capable of demonstrating the effects of hydrological, planning and economic parameters (Volume B).

6. A review of methods to determine a set of procedures applicable in Ontario to aid in evaluating flood plain management criteria (Volume C).

During the first phase, two sets of questionnaires were prepared and distributed. The first questionnaire was sent out to Conservation Authorities and Ministry of Natural Resources administrative regions. The second questionnaire was

distributed to various municipalities, organizations and individuals (Volume D).

The second phase consisted of policy formation. During this phase land use controls suitable for flood plain management in Ontario were investigated and possible management alternatives were outlined for flood plain regulations.

The alternative flood plain management policies were screened during the third phase with the aid of a computer-based mathematical model.

The report prepared during the final phase of the study was organized into an Abstract, a Summary Report and four volumes of working papers with the former two sections contained herein.

The Summary Report is basically divided into three parts, which describe various aspects of flood plain management which are relevant to Ontario.

The first part, Chapters 1 to 4, includes the introduction and describes the historical background, basic hydrology and statistical concepts.

The second part, Chapters 5 to 7, describes planning and overall flood plain management alternatives. It includes a survey of Ontario, U.S. and overseas practices, together with a brief description of methods to be used for selecting alternatives, including modelling.

The third part, Chapter 8 concentrates on the assessment of alternative policies for Ontario.

A selected list of references is included in the Summary Report.

Four separate volumes listed below incorporate the twelve working papers and reference material prepared during the study.

Volume A -	I	Flood Plain Management: The State of the Art
	II	In Ontario
	III	In Canada
	IV	In the United States
	V	International
Volume B -	VI	Hydrology
	VII	Computer Modelling
Volume C -	VIII	Historical Flood Damages
	IX	Methods of Assessment of Flood Control Alternatives
Volume D -	X	Land Use
	XI	Study Questionnaires
	XII	Institutional Aspects of Flood Plain Management

3. HISTORICAL BACKGROUND

Accounts of flooding in Ontario date back to times of earliest settlement. While their occurrence was at first regarded as an inevitable hardship, the interruption of community services together with the loss of jobs and taxes spurred the first attempts to plan for adequate flood controls. These early efforts and a concern that the Province's natural resources should be preserved culminated in 1946 with the passage of the Conservation Authorities Act. Since that time, Conservation Authorities have assumed a key role in watershed planning and water resource development with flood control remaining a primary activity. The occurrence of Hurricane Hazel in 1954 with its devastating floods and human suffering accelerated the development of a provincial flood plain management programme. To date the Conservation Authorities, in administering this programme, have invested in excess of $170 million for flood plain management.

Provincial flood damage figures for the period following 1946 are incomplete with information primarily limited to major events such as the $75 million loss during Hurricane Hazel, or the more recent flood in the Grand River watershed in 1974 which caused $7 million in direct damages. While severe flooding on major watercourses attract widespread attention, damages due to frequent inundation and to flooding of smaller streams are a continuous source of disruption to local communities. Between 1950 and 1970 over 430 floods were reported in Provincial newspapers with residential dwellings experiencing the most notable flood water damages. Despite the continuing flood losses during this period, the flood plain management efforts proved to be effective; urban development pressures had

only perceptably increased damage levels - an unique experience in an industrial society.

While the flood damage reduction benefits of the current flood plain management programme were acknowledged, the implementation of land regulations to prevent further flood plain encroachment was often frustrated. Undeveloped flood plain lands had not only retained the qualities that originally had attracted settlement but the proximity to existing communities further enhanced their development potential. Perhaps the most important perceived impact of a regulatory approach to flood control was on community development. The loss of assessment from the zoned flood plain lands was questioned in light of anticipated tax increases on other properties. In addition, with the elimination of building sites which had become most attractive as a result of government flood subsidies, development reportedly was more expensive. Members of the community with interest in growth were understandably concerned about the possible decrease in the relative attractiveness of their community.

Flood plains are occupied because it is convenient and profitable to do so but rivers periodically exert their rights and their occupancy is purchased at a price. Therefore, while a principal objective of flood plain management is the allocation of land to its most appropriate use from the viewpoint of the community as a whole, the nature and degree of occupancy should also be compatible with the risk factor involved. Accordingly, in view of the future population growth and urbanization and in light of changing government priorities, particularly in the field of housing and related urban developments, a thorough re-examination of present Flood Plain Management Policies was undertaken at the request of the Ministries of Natural Resources and Housing.

FLOODS REPORTED IN NEWSPAPERS 1950 - 1970

Scale in miles

20 10 0 20 40 60 80 100 120 140 160

LEGEND

BOUNDARIES

International — County or District

Provincial — Regional

RM Regional Municipality

(Excluding Hurricane Hazel)

● Floods

✸ Floods with danger to life

Figure 2

ONTARIO, MINISTRY OF TREASURY, ECONOMICS AND INTERGOVERNMENTAL AFFAIRS
REGIONAL PLANNING BRANCH

indicate that 65% of damages were incurred by the residential sector, 25% by commercial establishments and the remainder by industrial and institutional land uses. In the survey, water levels were cited in the majority of flood events as the major cause of damage. However, ice, sediments and water velocity are also mentioned in a significant number of cases. The analysis of the reported flood events revealed an increase in the number of occurrences while a similar investigation of flooding by land use suggested a slight upward trend in the number of floods affecting all land uses with the exception of the industrial classification. A further review of structures flooded tended to confirm that there was a slight increase in the extent of the residential damage; other land uses remained relatively constant.

4. HYDROLOGY

4.1 Introduction

The majority of flood events experienced in Ontario are produced by snowmelt which may be accompanied by rainfall; however, intense rainfall occurring during either the summer or fall seasons has also been responsible for severe flood peaks. During the study a review of the historic flood file maintained by the Conservation Authorities Branch, Ministry of Natural Resources, confirmed the foregoing observations. For the period from 1950 to 1970, the newspaper clippings documented 430 floods with 300 events directly linked to winter-related causes. Most summer storms, noted in the historical file, involved less than 3 inches over a 12 hour period. Hurricaine Hazel in 1954 and the Timmins storm in 1961 exceeded this rainfall and are regarded as the two major storms recorded over this period.

Due to this localized nature and short intense rainfall, thunderstorms are most effective in producing heavy runoff within small drainage basins. However, decadent tropical storms with their longer duration and greater areal extent must be considered when defining the flood hazard in larger watersheds.

A review of tropical storms such as Hurricane Hazel has revealed that over a period of 70 years between 1900 and 1970, 25 hurricanes passed or came close to Ontario; eight of these were of extraordinary severity with high winds and excessive rainfall. It is therefore apparent that any tropical storm which appears in the western Atlantic, Caribbean Sea or Gulf of Mexico is a threat to the Province


1 in 100 year flood
or
TIMMINS
zone 3
(same for Northern Ontario)
1 in 100 year flood
ZONE 2
HAZEL
ZONE 1
NORTHEASTERN ONTARIO
EASTERN ONTARIO
CENTRAL ONTARIO
SOUTHWESTERN ONTARIO
Québec
United States
LAKE HURON
LAKE ONTARIO
LAKE ERIE
GEORGIAN BAY
LEGEND
BOUNDARIES
International
Provincial
County or District
Regional
RM Regional Municipality
DM District Municipality
Approximate Regional Storm Boundaries
Scale in miles
20 10 0 20 40 60
ONTARIO, MINISTRY OF TREASURY, ECONOMICS AND INTERGOVERNMENTAL AFFAIRS
REGIONAL PLANNING BRANCH

Figure 3

of Ontario and should be watched with concern until it has completely dissipated or moves eastward into the Atlantic Ocean.

Similarly the meteorological conditions associated with the Timmins thunderstorm could occur in northwestern, central and southern Ontario; therefore that storm may be transported to all areas of the province with the possible exception of the extreme north.

4.2 Regional Storms

The Conservation Authorities Act states in part that an authority may make regulations "prohibiting or regulating the construction of any building or structure in or on a pond or swamp or in any area susceptible to flooding during a regional storm and defining regional storms for the purposes of subject regulations." The regional storm concept originated to provide protection from the heavy flood damages and loss of life that were experienced with Hurricane Hazel and the Timmins storm. The regional storms used to establish flood lines for different regions of Ontario have been determined in accordance with their geographical and meteorological occurrences by the Conservation Authorities Branch, Ministry of Natural Resources. The boundaries of the three hydrologic zones outlined in the following text are shown on Figure 3. Presently, Hurricane Hazel has been designated as the regional storm for central and southwestern Ontario but may be superseded by the 1 in 100 year rainfall where it results in higher peak flows. Similarly, the Timmins storm and the 1 in 100 year rainfall are employed in the area extending from eastern Lake Ontario through northern Ontario with the 100 year flood used in parts of northern Ontario where spring runoff due to snowmelt-rainfall is the dominating flood event.

In eastern Ontario the regional storm is defined as the rainfall, snowmelt or the combination of two which would generate a peak flow with a return period of 100 years.

These are calculated either by predicting on the basis of existing stream records or in the case of 1 in 100 year flood events due to rainfall, are predicted by generating synthetic hydrographs for peak flows using rainfall frequencies based on the recorded data.

The assignment of Hurricane Hazel and the Timmins storm as regional storms is on the basis of their occurrence as the largest flood producing events in Ontario that have been recorded in recent times.

The frequency of occurrence of these storms is not susceptible to an accurate statistical determination; nevertheless, it is known that they are not representative of the most severe hurricane or thunderstorm events. The maximum probable rainfall, the greatest to be expected, in Ontario has been estimated(1) for the two major storm types. The frequency of this rainfall is commonly estimated to be once in ten thousand years. To illustrate the relative severity of rainfall generated by the three regional storms and the maximum probable, the following six hour rainfall values over a 10 square mile area were selected:

1 in 100 year - 3.4 inches;
Timmins storm - 5.0 inches;

1 *J. P. Bruce "Preliminary Estimates of Probable Maximum Precipitation Over Southern Ontario" Engineering Journal Volume 40, Number 4, July 1957.*

Hurricane Hazel - 7.1 inches;
Probable Maximum Tropical Storm - 11.8 inches;
Probable Maximum Thunderstorm - 16.1 inches.

The determination of the flood frequency produced by a regional storm is further complicated by the fact that the time of occurrence and storm characteristics such as the rainfall distribution can significantly alter flood flows. Therefore, the return period of a storm does not necessarily equal the return period of the flood peak caused by the same storm.

Severe thunderstorms such as the Timmins storm usually follow a hot and dry summer period when interception and initial loss of rain due to infiltration are likely to be a maximum. However, a tropical storm is usually preceded by light to moderate precipitation in the vicinity of a slowly moving cold front resulting in more saturated ground conditions and a higher runoff to rainfall ratio.

Accordingly, Hurricane Hazel type storms will yield a higher percentage of total rainfall as runoff due to soil conditions preceding the storm.

4.3 Present Methods of Flood Flow Prediction

The most widely used methods used in Ontario to predict stream flows for flood management studies are: the statistical analysis of streamflow records; flow synthesis including the Rational Method for small drainage areas and the unit hydrograph method such as developed by the United States Soil Conservation Service.

At present, the estimation of flood flows by frequency analysis is limited to the eastern and northern portions of the Province where snowmelt related events may predominate. Despite the fact that the Water Survey of Canada collects streamflow data at approximately 475 stations throughout Ontario, the frequency approach is generally restricted to streamflow recording stations on major rivers with long periods of record. The absence of a regional frequency analysis whereby estimates of flood peaks are transposed in hydrologically similar areas currently dictates that flow synthesis must be employed at ungauged stream locations. A valuable insight into the relationship between flood characteristics and hydrologic features of drainage basins has been provided through water resource research at Queen's University but at present this information is of limited scope for province-wide application.

Both the Rational Method and the Soil Conservation Service Unit Hydrograph Method were developed in the pre-computer era and are presently being superseded by more advanced techniques which are gradually being implemented.

Hydrologic computer modelling is presently accepted as the state of the art method for simulating the interaction of hydrologic watershed parameters. A wide selection of model types are available to satisfy different needs and several studies based on these methods have recently been initiated by the Metropolitan Toronto Region Conservation Authority, and other agencies such as the Canada-Ontario Storm Drainage Committee.

Currently, there is no generally approved method in Ontario for predicting peak flows in ungauged areas where major flooding is caused by snowmelt or snowmelt plus rainfall.

Methods are, however, being developed by different agencies including the Ontario Ministry of the Environment. The need to colaborate these hydrologic methods on experimental watersheds is increasingly becoming evident. The use of general parameters developed for average United States conditions may lead to serious errors when applied in Ontario unless properly adjusted to more realistically reflect Ontario conditions.

The subject of calibration has also become particularly important in the application of flood synthesis models to urban watersheds. Traditional hydrologic methods originally developed for rural conditions must be used with care in these applications until changes in the hydrologic regime can be related to urban development with a high degree of certainty. A more comprehensive investigation of hydrologic changes in urban areas is required.

4.4 Selection of Estimation Techniques

The state of the art of flood prediction is evolving at a rapid rate and becoming increasingly complex with a wider scope of application in combination with socio-economic planning programs. With the variety and possible range of application of methods available today, engineering judgment plays a large role in the selection of prediction methods for particular applications.

In the context of flood plain management, flood flows can be defined by three distinct categories of hydrologic prediction:

1. ungauged areas;
2. gauged areas with short record periods;
3. gauged areas with long record periods.

A developing watershed will pass through different stages of the above phases. The degree of development and economic value of the lands usually reflects the order of prediction and complexity of analysis justified. The most opportune time to formulate the necessary program for data collection and detailed studies needed for each category of prediction is before development pressures occur.

In ungauged areas peak flow formulae can be developed relating basic and storm characteristics by regression and correlation analyses. Complete hydrographs can be generated with a regional unit hydrograph based on observed hydrographs from a similar physiographic area. Modelling with parameters calibrated in similar areas can also be considered. Hydrologic models are used for low and high flows and for the generation of time series of peak flows including moisture conditions. The same model may be used for several watershed studies and arbitrary assumptions regarding antecedent conditions may be eliminated. The calibration of the model gives a feeling for the unavoidable approximation of any computation. Furthermore, as described in Section 7.2, they can be interfaced with damage and economic models.

In gauged areas with short periods of record as found in the rest of the Province, the stream flow information can be used for the calibration of a rainfall-runoff model and subsequently extended using only meteorological information. The results obtained from modelled areas can help to improve the estimation procedures used in other areas. This approach has been selected recently by the Metropolitan Toronto Region Conservation Authority.

In gauged areas with long periods of record detailed frequency analyses of streamflow records adjusted to reflect land use

changes could be completed. A study of runoff characteristics based on recorded hydrographs and observed rainfall data could be used to accurately simulate a regional dimensional hydrograph and to develop regional and peak flow frequency formulae.

4.5 Flood Frequencies and Risks

The main purpose of any statistical analysis of observed flood series is to determine the return periods of recorded events of known magnitude and to estimate the magnitude or frequency occurrence of events beyond the recorded range. This is represented by fitting a theoretical mathematical probability distribution function to an observed settled data period. The most widely used probability function in Ontario is the Gumbel extreme value and Log-Pearson III distributions. However, there does not appear to be one probability distribution which best suits various observed flood series in Ontario.

Although a number of distributions should be tested to select the best fitting one, it has become standard practice in the United States to use Log-Pearson III in order to standardize the computation.

The use of predicted average recurrence intervals of flood events requires careful interpretation. A 1 in 100 year flood does not mean that flood conditions will occur once every hundred years but that flood conditions will occur on an average once every 100 years and that during any one year, there is a 1% probability of occurrence. On the other hand, for example, there is a 39% chance that the 100 year design flood will occur in any 50 year period.

If statistical analysis of a flood series is to be considered valid, each event in the series must be a sample from the same population, and each event must be caused by factors common to all members of the series. Flooding at a particular location may be due to an ice-jam, snow melt, thunderstorm or a hurricane. Rainfall occurring during saturated ground conditions at the end of spring will result in higher flows than the same rainfall occurring during the drier earlier fall period. Thunderstorms may occur in a particular region in a period only from June to October. Although the natural phenomena of flooding may be physically the same, the meteorological and hydrological conditions could be different.

A statistically homogeneous flood series can be compared by segregating floods by their obvious genesis such as snow melt, rainfall, ice-jamming and hurricane; the meteorological region of the rainfall events such as thunderstorm or hurricane occurrence; and by season if the existing flood seasons are not of the same nature.

Generally, in Ontario flood series obtained from any data can be segregated into four distinct populations each with their unique causative factors.

These are:

1) flooding occurring during spring runoff due to snow melt or snow melt plus rainfall;

2) flooding during the summer and fall periods due to rainfall;

3) flooding during the winter due to sudden thaw with rainfall or without; and

4) flooding due to man-made controls.

In discussing the reliability of flood frequency estimates, it is pertinent to examine the underlying assumptions made in computing the frequency curve and to assess the value of the result. The basic assumptions are: (1) that each flood occurrence on the river under study is independent, that each occurrence is a random event having no connection with other events in the series; (2) that all flood occurrences are homogeneous and members of one family; and (3) that the recorded floods are representatives of future floods.

The third basic assumption that the historical records are representative of the future introduces some doubt. Even when events are random, groupings of high and low values do occur.

It can be shown mathematically that if 10,000 years of record were available, the one hundred year flood would have a probable distribution as follows:

37 centuries would have no 100 year flood	=	0 flood
37 centuries would have 1 - 100 year flood	=	37 floods
18 centuries would have 2 - 100 year flood	=	36 floods
6 centuries would have 3 - 100 year flood	=	18 floods
1.5 centuries would have 4 - 100 year flood	=	6 floods
0.5 centuries would have 6 - 100 year flood	=	3 floods
100 centuries would have		100 floods

Although the return period has been used widely as a risk criterion, it has grave disadvantages unless it is translated into terms of other criteria. Given a particular return period, it is not at all clear what risk is being undertaken in a specified engineering operation.

The design return period cannot be realistically discussed without the possible benefits or losses involved, whether these can be explained in monetary terms or not.

In order to provide the complete picture, three components are required to describe the design criterion, 1) Design return period (T); 2) Design life (L); and 3) Risk of failure during design life (r). These three are related by the equation

$$r = 1-\left(1-\frac{1}{T}\right)^{L}$$

The design life depends on social and economic factors rather than on hydrological ones. If loss of life is not expected and all benefits and losses are expressible in monetary terms, a design life of 50 years is recommended in the literature as a realistic figure.

The term failure used in the equation does not necessarily mean a structural failure. It signifies the fact that the assumed design flood could be exceeded which in turn could result in damages.

DESIGN RETURN PERIOD IN YEARS (T)

Risk of Failure	Expected Project Life in Years (L)		
	25	50	100
1%	2488	4977	9953
10%	238	475	950
22%	100	200	400
25%	87	174	348
39%	50	100	200
50%	37	73	145
62%	25	50	100

Assuming that development in the flood prone area is designed for a 50 year period of expected project life and a 10% risk of failure of that development is permissible, than we require a 475 year return period design flood to meet the specified risk. If the development is designed for a 100 year life period, than the design criteria should be increased to a 950 year flood.

Similarly a 100 year design return period would provide a 39% risk of failure for an expected project life of 50 years, and a 62% risk of failure for an expected project life of 100 years.

Even a 1000 year return period flood has a 5% risk of being equalled or exceeded in a 50 year period. Risk in practice cannot be eliminated, it can only be reduced to an acceptable level.

The reliability of estimated return periods is demonstrated by the City of Sault Ste. Marie's experience.

The City experienced severe storms in three consecutive years as shown in the following table:

Date	Rainfall	Return Period
1968 August	3.45 inches	Once every 50 years
1969 June	3.15 inches	Once every 40 years
1970 May	5.55 inches	Once every 100 years

The various methods available of calculating risks do not decide whether a risk should be undertaken or not, this judgment is, and rightly should remain, a management decision.

5. FLOOD PLAIN MANAGEMENT–ALTERNATIVES FOR FLOOD DAMAGE REDUCTION

5.1 General Description

The most important issue in selecting the design criteria is related to the aspects of risk and protection. The concept of providing complete protection from flood hazard cannot be regarded as a practical proposition. It is evident that there will always be a probability of floods higher than anything that was experienced previously. The problem, therefore, is to select an acceptable level of risk consistent with sound technical considerations and economics.

Since their inception in 1946, the Conservation Authorities have taken an active role in the flood control and management of the province's water resources. The authorities have invested in excess of $60 million between 1950 and 1970 for flood plain management purposes. An indication of the continued emphasis placed on water management programs by the Ministry of Natural Resources in recent years is demonstrated by the increase in grants to conservation authorities which totalled $9.7 million in 1970 and $31.4 million in 1975. Traditionally, water management programs equal between 40 and 50% of the total grant expenditures. Depending upon the nature of individual flood control projects and the provincial grant structure, the authorities will assess benefiting municipalities with a portion of project costs.

In stressing an integrated flood plain management program, preventive measures have been adopted in Ontario to direct flood prone structures away from hazard areas while corrective measures have been employed to reduce flood damage to existing development.

TABLE 1

ALTERNATIVES FOR REDUCING FLOOD LOSSES

Goal	Corrective		Preventive	Other
	Structural	Non-Structural		
Modify the flood	Dams and reservoirs levees or walls, channel improvements, stream diversion, storm drainage systems	Watershed treatment, meteorological modification, snow management, prevention or removal of ice jams.	-	-
Modify the susceptibility to damage	Flood proofing, fill and/or elevate new structures, relocation	Evacuation and emergency flood fighting measures. Flood forecasting and warning systems. Urban re-development.	Regulations -To disclose flood hazard in real estate transactions. -For subdivision development -For sanitary and health -For encroachment and fill Zoning bylaws Building codes. Development policies Warning signs and education programs. Public and private purchase of open space for easements. Tax adjustments for open space.	-
Modify the loss burden	-	-	-	Flood insurance, tax write-offs.relief and rehabilitation, protection from looting.

Experience in the United States has shown that protective works will invite further intense flood plain development and subsequent greater flood damage when the works prove inadequate. To avoid this situation, the regulation and possible acquisition of flood prone lands have been actively pursued in Ontario to reduce property damage and forestall premature construction of structural measures. Table 1 summarizes the corrective and preventive measures available to reduce or to eliminate potential flood losses. The following is a brief summary of the more widely used flood damage reduction alternatives.

5.2 Modification of the Flood

Physical structures have been the principal means of flood control in the past. The primary reason for this is that structural solutions can be easily implemented to protect existing development. While these works are effective to the magnitude of the selected design flood, when such floods are exceeded, substantial damages can result. Environmental aspects of structural flood control measures can substantially reduce the functional and economic aspects.

Flood control reservoirs have been widely used in the past. The scarcity of available sites with acceptable construction and environmental costs has resulted in a marked reduction in the building of dams and reservoirs. As dams can rarely provide protection from the maximum probable flood, especially in larger rivers, development downstream after the construction of the dam could still encroach on the ultimate flood plain.

Traditionally, reservoir projects under the Conservation Authorities jurisdiction have been developed on the basis of multi-purpose use of water. However, uses including flood control, urban water supply, irrigation, pollution abatement, maintenance of low flow and recreation are often incompatible. These conflicting demands coupled with environmental considerations have slowed the construction of reservoirs in recent years.

Dyking projects which are often accompanied by a form of channelization have been used for the protection of agriculture lands and urban areas, for example, the proposed reconstruction of 22½ miles of dyking in the Township of Dover for a cost of $8.7 million to protect low lying agricultural lands subjected to high Lake St. Clair water levels. Dykes could ultimately be overtopped by floods of greater severity than the protection level, often resulting in widespread property damage and loss of life.

Channel improvements are common and numerous schemes have been implemented throughout the province to lower flood levels in hazard areas by increasing waterway capacities. While channelization does provide relief from periodic inundation, officials have been increasingly aware that adverse environmental changes may be introduced due to increased discharge velocities and flood peaks.

Non-structural methods such as watershed treatment, e.g. tree planting, etc., meteorological modification and prevention of ice-jams could play a minor role in flood protection in Ontario.

5.3 Modification of Damage Susceptibility

Flood plain regulation is the most commonly used alternative under this category.

The regulatory approach sets guidelines which determine permissible land use within the flood plain. Regulation cannot reduce the risk to existing flood prone development but existing non-conforming uses can usually be brought into conformity by flood proofing.

The basis of flood plain regulation lies in accurate mapping and determination of flood levels. If regulations are to be successful they should serve as a guide, be reasonable and non-discriminatory rather than totally prohibitive. Techniques for applying flood plain regulation are subdivision controls, building codes and zoning. Subdivision regulations can specify the manner in which the land may be divided but building codes implement construction techniques which can reduce damage in the flood plain.

In Ontario, the Conservation Authorities Act provides a mandate to the Conservation Authorities to regulate activities within flood plains delineated by the Regional Storm. An appeal procedure assigned to the Mining and Land Commissioner, Ministry of Natural Resources, provides some flexibility in the application of the regulations.

Two district zoning is the most widely used system in the United States and was recently recommended by the Department of the Environment for Canada as part of the National Flood Damage Reduction Program. It is widely viewed as a compromise between recognizing the hazard in flood plain use and accommodating urban land requirements. In the two-zone ordinance, the key zone is the floodway which is intended to pass a design flood. The second is the floodway fringe. Both are contained in the area defined by the extent of the regulatory flood. Encroachment in the floodway, whether in the stream or adjacent overbank area is prohibited, whereas the fringe is available for more intensive use if adequate flood-proofing measures are taken.

Tax adjustment provides the owner of flood plain land a relief to his tax burden, however, the main problem in devising a differential taxation scheme appears to be in defining an acceptable method for recovering taxes in the event that the flood prone land was ultimately developed.

Flood-proofing is a structural alternative which can reduce the damage associated with a given level of flood and can be regarded as a permanent or as an emergency measure. Building codes and regulations require special detailed design and construction methods to assure acceptable uniform application by flood plain users. Only moderate flooding characterized by shallow depth and low velocity can be economically flood proofed.

Urban redevelopment can provide an excellent opportunity to remove or permanently protect properties situated in the flood plain as demonstrated in Timmins.

Flood warning requires large watersheds with long response times to allow sufficient time for emergency flood-proofing, evacuation and flood fighting measures.

Flood forecasting is carried out by the Conservation Authorities Branch, Ministry of Natural Resources, and flood advisories are issued through the conservation authorities. The spring runoff season remains the most active period for this activity with the snow melt related events being the causative event in more than 80% of flood damages. With the exception of a few large rivers in Ontario, the economic benefit of flood warning systems may be limited due to the quick response of rivers, to rainfall or snow melt events and the corresponding lack of appropriate warning time to affect evacuation measures. Nevertheless, the Government of Ontario has recently identified the Ministry of Natural Resources as the ministry responsible for provincial response to flood emergencies.

Flood insurance which modifies the loss burden is used in the United States as an alternative for reducing flood losses. See page 51 for further comments.

6. FLOOD PLAIN MANAGEMENT PRACTICES

6.1 Province of Ontario

6.1.1 Introduction

The present goals of flood plain management policies in Ontario reflect most of the current objectives in the fields of flood damage abatement and water resource planning, namely:

1. the prevention of human suffering and loss of life;

2. the alleviation of damages to existing flood plain development;

3. the prevention of encroachment into flood prone areas by new development;

4. the improvement of land use practice in flood prone areas thereby eliminating uneconomic, hazardous and unnecessary activities; and

5. the creation of a safer and better environment.

6.1.2 Existing Land Uses

Information from more than 20 different agencies was collected during the study to assemble an overall picture of land use in Ontario pertinent to flood plains. The detail and quality of data varied considerably from one agency to the other and in-house studies were necessary to relate the land use data to flood plain conditions. Results should be treated as approximate; nevertheless they do identify many problem areas.

The examination of land use indicated that flood plains encompass between 6 to 7 per cent of the total municipal land area throughout Ontario. This value is lower than in the United States where a similar survey provided a value of 10.5 per cent.

A significant portion of the urban flood plain in the Province is concentrated in four municipalities with more than 50 per cent in Metropolitan Toronto, the Regional Municipality of Peel, the City of London and the City of Brantford. One-third is located in Metropolitan Toronto alone. In general, less than one-half of the flood plains are developed, with an average distribution of land use as follows:

Residential	14.3%
Commercial	3.3%
Industrial	8.1%
Institutional	5.0%
Open Space	24.6%
Vacant or Agriculture	39.6%
Other	5.1%

The land use calculations indicate that flood plain lands do not involve a significant portion of the urban areas which were reviewed.

During the study an attempt was made to derive generalized estimates of the value of development within the flood plain areas. This value was derived by establishing the value of development costs per acre for residential, commercial, and industrial land uses. Based on a survey of 25 urban centres, the residential development in flood plains has been estimated to exceed $475 million. Similar calculations for industrial and commercial developments resulted in $220 and $60 million

respectively. Therefore, the total estimated residential, commercial and industrial value of development in the flood plain areas exceeds 3/4 of a billion dollars.

In assessing the general trends in flood plain development one finds that the expanding 60's was a period of increasing urban development. During this period the conservation authorities gained considerable experience in flood plain management and provided an invaluable input into the advancement of the land use planning in Ontario. The effectiveness of the conservation authorities in this period has been shown through the responses to the questionnaires which indicated that 75% of the urban flood plain development occurred in the period prior to 1950.

Significantly, the questionnaires revealed that 47 per cent of the applications for development within flood plain lands originated from private landowners, 35 per cent from small developers and only 17 per cent from major developers. The remainder came from municipalities, provincial agencies or other sources. In many cases, development pressures from small private landowners were more difficult for Conservation Authorities to handle since design options were often limited by fixed site boundaries and limited resources.

Nevertheless, during the 60's land use planning matured and many municipalities began to incorporate watershed management considerations into the development of official plans.

A review of the municipalities which have experienced flooding indicates that many problems involve small rural towns or rural townships adjacent to major urban centres. Flood plain regulations have been successful in controlling new development but have been less than successful when applied

retroactively to non-conforming uses. Numerous factors influence both urban development patterns and the successful development of a flood plain management programme. In urban centres where the flood plains have well-defined valley systems and significant scenic attributes, only limited development has taken place on the flood plains. However, in northern Ontario there has been significant flood plain development in some urban centres; limited building sites in the surrounding terrain is commonly cited as a major contributing factor.

Flood events involving major flood damage and the loss of life appear to have a mixed effect upon infrequent flood plain encroachment. For example, in the Metropolitan Toronto Region current land uses in the valley areas are a result of the flooding produced by Hurricane Hazel and management programs that have evolved after that catastrophic event. Generally, where relief compensation is given, hazard perception remains low and flood plain development persists. Past flood events such as the 1974 flood on the Grand River has not appeared to appreciably increase hazard perception of flood plain users.

6.1.3 Institutional Framework

Various aspects of water resource management in Ontario are administered by six provincial ministries and the Hydro Electric Power Commission.

Flood plain management programs in Ontario can trace their origins to the policy initiatives of the Conservation Authorities Branch of the former Department of Planning and Development, later the Department of Energy and Resources Management and currently the Ministry of Natural Resources.

This branch has traditionally been given the lead role in matters relating to flood plain management and general conservation. With responsibility for the administration of The Planning Act, the Ministry of Housing also plays an important role with respect to development in the province's flood plains.

Several other ministries are responsible for programs and policies that affect the nature of flood plain management. The farmland drainage programs of the Ministry of Agriculture and Food and the environmental policies and programs of the Ministry of Environment are further examples of such government activities.

While numerous legislative acts are employed for water resources management within the province, three documents are considered most relevant to flood plain management and associated land use regulations:

1. The Lakes and Rivers Improvement Act

While in its broadest sense the Lakes and Rivers Improvement Act, passed in 1927, prohibits the disposal of matter in the waters or adjacent shore properties, the primary intent is directed to the regulation of dam construction and other works on lakes and rivers. Conservation Authority dams are specifically excluded from this legislation. In the early years after the legislation was passed, the majority of dams were constructed for log driving, water supply and power generating purposes. An increasing tendency in recent years to construct small structures for recreation purposes has led to many private impoundments, most of which are unauthorized. A recent task force estimated that approximately 75% of the private dams in Ontario, numbering in excess of

2,600, were not approved under the Lakes and Rivers Improvement Act. Recently, the field offices of the Ministry of Natural Resources have been authorized to approve the location and plans for these dams, which hopefully will streamline the approval process.

In 1971 an amendment to the act recognized the need to protect fish resources in the rivers. While further review of the act continues in relation to fisheries and habitat management requirements for the province, one possible limitation to its applicability to overall flood plain management has been noted. It appears that the powers of the act as applied to the overbank areas adjacent to normal waterways, may be limited and subject to legal interpretation.

2. The Conservation Authorities Act

The Ontario Legislature passed the Conservation Authorities Act in April 1946. The Act provided for the joining of all municipalities of a watershed desiring a conservation authority into a corporate body, for the purpose of effecting conservation measures. To function successfully each individual conservation authority has to look to the other levels of government for both co-operation and assistance. However, the authorities do not have a major working-relationship with the Canadian Federal Government. The act has been amended several times since 1946 and has been reviewed again recently.

In administering the present legislation, a number of procedures and guidelines have evolved in the context of sound water management practices and a general response to pressures of urban development.

(a) Regulation of Flood Plain Lands

While present jurisdiction by conservation authorities over waterways extends to headwater areas of all drainage basins, this enforcement of regulations is generally not exercised within watersheds which are smaller than ½ square mile. Within urban areas drainage basins of this size are considered ultimately to be enclosed by storm sewer conduits; therefore, the responsibility for maintaining local drainage and headwater streams is delegated to the municipality. For those watercourses with a tributary drainage area exceeding ½ square mile, the regional storm flood line is applied for purposes of regulating flood plain development in watersheds located within a conservation authority.

In administering flood plain lands which are inundated by the regional storm, development of non-conforming land uses are normally prohibited from the entire regional flood hazard zone. Falling within this classification are all residential, commercial, industrial and institutional land uses which would incur substantial flood damages. Certain exceptions are made to the no encroachment rule, but these are judged according to their effect on resultant upstream and downstream water levels during the regional storm. Detailed investigations are commonly carried out to evaluate actual increases in flood levels, but acceptable increments are largely a function of the shape of the particular stream valley together with anticipated future development. In order to minimize any increase in the flood hazard area, a normal prerequisite to flood plain encroachment imposed by the authorities is the rule that the volume of filling on the flood plain below the regional storm flood line must be balanced by removal of an equal volume of fill at corresponding elevations.

A number of conservation authorities have followed a policy of land acquisition to restrict further construction on the flood plain in urban centres. Levels of funding and continuing maintenance requirements of parklands are cited as major limitations to this approach.

(b) Remedial Flood Control Works

Structural flood control works including reservoirs and channelization have normally been constructed in Ontario as remedial measures which will minimize potential flood threats to existing development. Pressures for new development in existing areas commonly are experienced after these protection measures are implemented. Remaining reservoir sites throughout the province often do not possess the storage capacity to substantially alter regional flood lines. However, in some cases benefit cost investigations have indicated a favourable reduction in flood damages inflicted by more frequent flood events.

(c) Applications for Development

Regulations presently adopted under the Conservation Authorities Act empower the executive committee of the conservation authority to rule on applications to either fill or construct within the regional flood plain or alter existing waterways. At the same time the proponent is required by the local municipality to obtain a building permit subject to applicable zoning by-laws. Proposals for larger developments including subdivisions also must qualify for an authority's fill and construction permit, but in addition, the authority is requested to comment on the proposal to the Ministry of Housing through the Ministry of Natural Resources. The authorities will provide guidance

to the potential developer at the initial stages of site planning generally advising on technical investigations which are required as a basis for the authority's final decision on the permit.

Refusal of a permit may be appealed to the Minister of Natural Resources and following a hearing by his designate, the Mining and Lands Commissioner, a final decision is issued with respect to granting a permit.

Flood plain cases suggest that in general, properly authorized regulations will be valid if they are adopted in compliance with statutory requirements, treat similarly situated individuals equally and are based upon sound data.

Courts have often approved regulations which reduce the value of lands, however, in cases where compensation is involved, the courts generally have found the assessment of compensation a rather difficult subject.

The legal system does recognize the fact that flowing water cannot be owned; however, common law does allow an owner of property beside a watercourse the right to use water in front of or on top of his land. Nevertheless, judicial support is strong in the control of encroachment in flood plain areas which may damage neighbouring properties by increasing flood heights and velocities or in land use control cases which serve broad objectives in promoting the social, economic and political well being of a community.

The Conservation Authorities Act 27-1 states: "an authority may make regulations applicable in the area under his jurisdiction" and (e) "defining regional storms for the purposes

of such regulations". Therefore, any possible future change in the design criteria would involve only a change in definition of the regional storm.

In (f) the act states: "prohibiting or regulating or requiring the permission of the authority for the placing or dumping of fill in any defined part of the area over which the authority has jurisdiction in which in the opinion of the authority the control of flooding or pollution for the conservation of land may be affected by the placing or dumping of fill."

The above definition would enable a conservation authority to stop any construction and fill in the floodway should a different zoning such as the two-zone concept be adopted at a future date.

3. The Planning Act

The Planning Act, first passed in 1947, was designed to complement the conservation legislation which emerged at about the same time. During this period the Provincial Government's conservation and land use planning programs were both under the aegis of one government department -- the former Department of Planning and Development. In the succeeding 30 year period, The Planning Act has been the primary tool by which municipalities have controlled the nature and location of development within their area of jurisdiction.

Since the Ministry of Housing is in a position to approve all municipal official plans and plans of subdivision as well as the review of zoning by-laws and local decisions on consent applications, it is automatically in a position to influence the nature of various municipal planning policies

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Since the Ministry of Housing is in a position to approve all municipal official plans and plans of subdivision as well as the review of zoning by-laws and local decisions on consent applications, it is automatically in a position to influence the nature of various municipal planning policies

that apply in these areas. In practice the Ministry exerts this influence through its role as a coordinating agent and final arbiter for a number of provincial agencies that comment on the appropriateness of proposed developments within the flood plains. The Ministry of Natural Resources provides most of the technical input which provides the basis for subsequent decisions. More recently, the Ministry of Housing has exerted a further policy influence through its community planning advisory function and financial assistance program for municipal planning studies. In municipalities without planning programs, the imposition of a Minister's order to control land use development represents another way in which the Ministry is able to exert influence on the nature of flood plain development.

Municipalities in Ontario can incorporate flood plain management practices into planning policies and regulations by virtue of the powers under The Planning Act. A review of a number of official plans indicated that flood plain policies very often do not exist in the plans, but are part of general hazard land policies which first emerged in municipal official plans in the late sixties. Open space policies vary considerably from municipality to municipality. Each municipality has plans allocating a number of acres per unit of population for recreation and open space. A number of plans place hazard lands, hence flood plain lands in that category. Hazard land designation includes all lands having environmental hazards such as poor drainage of organic soils, flood susceptibility, erosion, etc. Hazard lands are intended primarily for exclusion of people from areas where development could be dangerous but also for preservation and conservation of the natural land and the environment. Although the above is the most commonly used definition for flood

plain lands, occasionally the top of the valley designation is used whereby flood plain and hazard lands are included.

The methods of designating the line, whether hazard line or flood line, are frequently based on the local conservation authority mapping. This mapping may be for the fill lines, hazard zones, flood lines, top of the valley or occasionally areas designated as natural resource lands.

Most of the open space, hazard or flood plain sections have standard policies stating no tree removal or buildings allowed which would cause a reduction of the flood water retention capability. At times the fill lines may be mentioned, and in a number of plans institutional buildings are accepted and are allowed to locate on the flood plain. Generally official plans state that the permitted use of their flood plain lands are for recreation and conservation. This statement, however, relates to public flood plain lands only, but every plan makes provisions for private lands. Open space policy within the various official plans consistently lists recreation and conservation as permissible activities on the flood plain. Commonly listed are the following open space uses:

1. Cemeteries
2. Golf courses
3. Nursery gardening
4. Agriculture
5. Forestry

In some cases official plans include policies for flood plain regulation in a section that specifically deals with hazard lands rather than open space. The extent to which policies are identified for these lands tend to vary

considerably from one plan to another. Many municipalities have simply identified the appropriate conservation authority as being responsible for regulating the land use development constraints. This approach is common among smaller municipalities which lack the administrative capability to implement planning policies in an effective manner.

Another approach for incorporating flood plain regulations in official plans is through the adoption of policies relevant to conservation lands. This represents an attempt to improve the hazard land concept and allows for the inclusion of specific ecological concerns. This approach allows for the potential development of such lands after they have been subjected to an appropriate analysis and implies a high degree of coordination between the local municipality and the conservation authority.

Very few municipalities have incorporated comprehensive flood-proofing measures into their zoning regulations for flood plain areas. Although this is an accepted practice in the United States, interviews carried out during this study revealed that most municipalities do not have the inclination or staff capability to become involved in the technical aspects of controlling development in the flood plain. Most municipalities would prefer to formulate broad land use policies for their flood plains, but leave the administration of detailed regulations for filling and flood-proofing with the conservation authorities.

6.2 Canada

Federal Initiatives

Under the British North America Act, the regulation of natural resource development is a provincial and not a federal responsibility, however, major floods have prompted the involvement of both levels of government in providing financial relief. Federal participation since 1969 has been through its Disaster Assistance Program in which direct federal contributions follow an established "dollar per capita" formula[1].

Concern about using disaster assistance costs and a reassessment of federal programs resulted in the announcement of the National Flood Damage Reduction Program by the federal Minister of the Environment in April 1975.

General Agreements to be negotiated by the Federal Government and each of the Provinces are to provide for joint funding to a flood risk mapping program based on mutually agreed hazard areas. Federal agencies such as the Central Mortgage and Housing Corporation and the Department of Public Works will not develop or support development in identified high risk areas and federal disaster assistance to new developments will also be refused within these hazard areas. As a prerequisite to the flood mapping programme, the Provinces under the General Agreement are requested to restrict investment in high flood risk areas and encouraged to adopt zoning regulations in such areas.

1 *"The National Flood Damage Reduction Program" J.P. Bruce, Director General, Inland Waters Directorate, Environment Canada, paper presented at Flood Plain Managment Conference; Canadian Water Resources Association, Nov. 1975.*

In order to ensure that the information presented on the flood risk mapping is as accurate as possible, federal guidelines have been assembled outlining hydrologic and hydraulic procedures to be followed.

The particular flood designated as the "design flood event" for purposes of defining flood risk areas may vary from province to province but will be one of these types:

i) floods based on probability;

ii) floods produced by a specified input such as a Regional Storm;

iii) large recorded floods.

However, the resultant water elevations must be no less than that of the 100 year flood. The question of whether to adopt a floodway and allow restricted development in the flood fringe is left to the discretion of such Province.

6.3 British Columbia

The control of flooding in British Columbia until recently has been accomplished with varying degrees of success by traditional structural measures. After the spring flood of 1972, efforts were directed towards planning and regulatory controls to meet the basic objectives which are reducing injury, eliminating loss of life and minimizing property damages by flood waters. A combination of approaches has been found to be the most workable solution to problems of flooding in developed areas. New development on flood plains has been regulated where possible.

Because of the mountainous terrain and hydraulic characteristics of rivers in the province, a design flood with a two hundred year frequency has been adopted for regulatory purposes. A flood plain mapping program based on this criteria was initiated. The flood construction level generally represents the profile of the two hundred year frequency flood plus a freeboard allowance to allow for errors in measurements and wave action. Generally, this freeboard is taken to be 2 feet.

In view of the limited availability of land in the province which is either mountainous or flood plain, encroachments into the above-noted flood plains are permitted but are subject to flood-proofing requirements. Habitable areas of buildings must be placed above the flood construction level either by landfill or structural elevation. Dykes and floodwalls are not considered adequate flood-proofing for extension of urban areas unless complimented by traditional flood-proofing measures.

In 1972 when steps to control flood plain development were initiated, all municipalities and regional districts were requested to incorporate flood control requirements into the zoning by-laws.

6.4 Province of New Brunswick

Most floods have occurred in New Brunswick in the spring as a result of snow melt and rainfall or ice-jams; but significant floods have also occurred in the late summer or fall as a result of heavy rainfall from tropical type storms.

The 1973 flood in the St. John River basin was a catalyst in the implementation of a provincial flood plain management

program. Flood risk maps of the Fredericton area delineating the limits of a 20 year and a 100 year flood have been completed in conjunction with the Federal Government. In 1976 the Province and Canada signed an agreement for the reduction of flood damages and an agreement regarding flood risk mapping. In most cases the intention is to map both the 100 year flood line and the 20 year floodway. The Province has recently initiated advanced studies for regional hydrologic investigations and flow modeling. Grants are given by the Federal Government under the foregoing programme. As a complimentary step in controlling flood prone development, the Provincial Government is now assembling appropriate legislative statutes to regulate future flood plain use.

6.5 Province of Manitoba

To date flood protection in the province has consisted of structural measures including both permanent and emergency flood control works. Generally, a minimum 1 in 100 year design level is provided with more conservative protection afforded as individual projects warrant. The greater Winnipeg floodway is designed to bypass flows approximating the 1 in 160 year flood.

In the absence of a formal provincial program of flood plain management, the Department of Municipal Affairs currently plays a prime role in discouraging unwise development in flood hazard areas. This agency formally reviews application for all new subdivisions with the assistance of other provincial departments. New development commonly is not permitted in flood prone areas unless the flood hazard can be prevented by permanent works without affecting other riparian owners. Zoning regulations imposed by individual

municipalities represent the only other institution control over flood plain use.

6.6 Alberta

Flood plain management has evolved in Alberta since the early 1950's when the Water Resources Division, Department of Environment began to review subdivision applications with respect to the potential flood hazard.

Although the Water Resources Division had no authority to prevent approval of a subdivision its recommendations were significantly influential on the decisions of the Regional Planning Commissions, and in a great many instances such proposals were rejected on the basis of these recommendations.

In 1960, provision was introduced into the Alberta Water Resources Act giving the Minister authority to establish flood control zones and to set forth terms and conditions regulating the use of lands within these zones. A further measure of control became available in 1966 when the Alberta Department of Agriculture established a Land Assembly Program for acquiring lands for special purposes, or lands where existing use was not suited to the land characteristics. Lands in flood plains that became available through tax sale or other circumstances, or the purchase of which was a preferred remedy to a structural flood control solution, were acquired by the Province.

To date structural measures have primarily been relied upon to deal with flooding problems, particularly in rural areas.

Depending upon the size and productivity of the affected land, desirable protection for agricultural land is generally to a 1:10 or 1:20 year flood.

In urban areas a greater attempt to use alternative methods such as land use planning and subdivision approvals has been made. Commercial, residential and urban development is discouraged within flood zones delineated by the 1 in 100 year flood. In general, the rapidly escalating social and economic costs of structural solutions has encouraged future consideration of additional non-structural alternatives including purchase-lease arrangements and relocation for both rural and urban application.

Under present legislation the Regional Planning Commissions or the Department of Municipal Affairs continue to regulate flood plain lands through the approval of subdivision applications or changes in zoning with the Department of the Environment providing a technical review. In addition, major industrial development requires approval by the Department of the Environment; this provides a direct method of ensuring that such developments are not allowed in flood prone areas. Appeals on the part of the applicant are made to the Provincial Planning Board.

To adequately evaluate subdivision or other development proposals, a programme of flood plain mapping has been initiated. This programme applies principally to major streams and rivers and information is made available to the public through regional planning commissions, counties and municipalities.

While development within the 100 year flood plain is generally discouraged, exceptions can occur when flood plain lands are

already developed or zoned for development and when planning authorities reject recommendations against such development. Owners of existing property in flood prone areas may also undertake development or improvements not requiring approval from a government agency.

6.7 Flood Plain Management in the United States

In the United States approximately 11% of the urban area is in the flood plain based on a 100 year flood criteria. About half of these urban flood plains have been developed. Early urban development within the flood plain led to flood protection by implementation of structural measures. More than eight billion dollars has been spent by the United States Federal Government since 1936 on such protective works. In spite of this the total amount of annual damages has continued to rise which is due to the continued urban encroachment into the flood plain. Current figures show that the cost to the nation of permitting uncontrolled development of flood plain lands averages more than $300 million annually.

Continuing urban development in the flood plain has led to the realization in the United States that implementation of non-structural flood control measures is required to compliment structural methods. The trend in the United States to implement regulation policies is similar to an established Ontario practise - the reduction of future damage susceptibility by preventing new development in the flood plain. Widespread implementation of flood plain regulations in the United States has been very slow because local levels of government are quite independent and have resisted the implementation of regulatory techniques.

The most effective factor in obtaining nation wide action on flood plain regulations has been the Federal Flood Disaster Protection Act of 1973.

One of the main objectives of the flood insurance program is to force communities to initiate a more comprehensive approach to flood plain management, including flood plain regulations. Local governments adopt flood plain regulations that meet or exceed minimum federal criteria in order to be eligible for flood insurance. Flood insurance is required in order to receive federal financial assistance for acquisition or construction purposes in identified flood hazard areas. While approximately 13,000 communities are participating in the National Flood Insurance Program on a provincial basis, the effectiveness of the implementation of the program is under review at the present time. Numerous positive and negative considerations of this approach to flood plain management have been identified. On the positive note, the following advantages can be listed:

1. Requires communities to address their flood related problems.

2. Sets out standards for land use and building codes in flood prone areas.

3. Discourages unnecessary use of flood plains by charging actuarial rates after the regular program is operative.

4. Differentiates between existing uses and new uses through risk rates.

5. Reimburses flood victims more quickly and fully than they would be through other federal programs.

On the negative side, the flood insurance program has the following disadvantages:

1. Increasing the possible future losses while encouraging the use of the 100 year flood as a limit to regulation rather than any higher regional flood.

2. It is unable to check abuses because the Federal Insurance Agency does not have a field officer to supervise implementation of land use regulations.

3. By providing insurance in some hazard areas may encourage lending institutions to support construction they formerly considered too risky.

A report concerning a unified National Flood Management Program is currently in preparation by the United States Water Resources Council. It is expected that the report will recommend a combination of approaches which would modify the susceptibility to damage by adjusting the pattern and mode of land use in flood plains in accordance with the flood hazard. The recommendation will include items such as insurance, relief, rehabilitation, reconstruction and the traditional structural measures. The expected report will result in continued development of an approach coping with flood hazards across the United States since a concensus of opinion must be arrived at by the various members agencies.

6.8 International

A review of the international literature revealed that the world-wide interest is growing towards a more comprehensive flood management approach. This could be due to the fact

that statistics show that floods are the number one world-wide natural disasters followed by typhoons, hurricanes and cyclones. Flood losses usually occur either due to a shifting emphasis to more intense agricultural use of the flood plain or due to urban encroachment in the flood plain after construction of initial protective works. In 1974 the United Nations Economic and Social Council prepared a provisional report on flood control planning in river basin developments. This report emphasized the advantages of a system of flood controls, based on permanent flood control committees at the central and local levels, consisting of representatives of all departments, establishment and social organizations. Most countries provide information on methods of calculating direct and indirect damages and flood frequencies. While some countries quote the 100 year level for riverine protection, special circumstances in deltaic regions may dictate a 10,000 year figure for densely populated and heavily industrialized areas.

Owing to the increase in economic and social requirements it is now becoming essential in Europe to consider the possibility of developing flood plains, mainly for agricultural purposes. In most countries covered by the United Nations study, the land is zoned by degree of risk and its use is planned accordingly. This is most practical for large river basins where improved and automatic hydrological and meteorological warning systems can greatly reduce the element of surprise.

The following general points summarize international flood plain management practices:

1. Structural flood control measures continue to be used to a large extent, predominantly reservoirs and levee systems.

2. World-wide increases in urbanized areas on flood plains have led to increasing annual flood damages. This is generally leading to implementation of non-structural flood management measures such as flood warning, building regulations and zoning.

3. Flood damage information and cost benefit analysis methods are less well defined than for the North American continent.

4. The required level of protection is not well defined on a world-wide basis. While some countries rely on individual cost benefit analysis in order to select a level of protection, other countries use predetermined level of protection such as the 100 year flood.

7. EVALUATION OF FLOOD MANAGEMENT POLICIES

7.1 Assessment Procedures

In the assessment or evaluation of flood plain management alternatives, the planner is immediately faced with two questions:

(1) What is the best mix of measures (structural and non-structural) to be employed?; and

(2) For what level of flood protection (flood frequency) should they be planned?

If the decision on the flood management plan is to be made on economic grounds, consideration must be given to the benefits (or damages averted) from flood control, the costs of adopting the management plan and their distribution between groups in society. Since different flood management plans perform differently, it is necessary to assess the benefits due to alternative measures individually. For example, structural and non-structural alternatives designed for the same flood frequency will produce different residual damages and hence benefits. Therefore, they cannot be treated equivalently, and each must be measured against their costs not only to determine which alternative is preferable but also to determine the optimal level (frequency) of flood to be managed.

The costs of flood control projects are all opportunities foregone by undertaking the plan. These include not only the capital expenditures on structures but also the income foregone by restricting flood plain land use. The benefits experienced from undertaking a flood control project are all

the direct and indirect results of the project for which beneficiaries would be "willing to pay". These benefits include damages averted (directly and indirectly) and the secondary, intangible, and uncertainty benefits due to the project.

Traditional economic analysis of flood control alternatives has generally assumed the straightforward objective of maximizing the net benefits (total benefits minus total costs) that accrue to a project. A variety of well known techniques exist for this purpose such as marginal benefit-cost analysis and various systems analyses techniques such as mathematical programming. However, objectives other than economic efficiency are more frequently entering the evaluation of water resource projects. These additional objectives are both economic (such as benefit allocation and distribution) and non-economic (non-commensurable objectives such as social well being, environmental quality, loss of life, etc.) in nature. Therefore, newer evaluation techniques have emerged which go beyond the bounds of net benefit maximization.

Techniques for permitting these extended analyses fall into two categories:

(1) techniques which allow the analysis of other quantifiable economic objectives; and

(2) techniques which include into the analysis of unquantifiable, non-commensurate objectives.

Techniques of the first category deal with problems of allocation and distribution of project costs and benefits and are referred to as techniques of incidence analysis.

Techniques of the second category deal with problems of the evaluation of intangibles. Incidence analysis procedures vary from distinguishing beneficiaries and benefactors and weighting these benefits in the objective function to the development of incidence matrices which illustrate the incidence of benefits on different population groups.

Techniques available for the evaluation of intangibles fall into three categories:

(1) monetary evaluation procedures;

(2) non-monetary evaluation procedures; and

(3) future options approaches.

Monetary evaluation procedures attempt to place approximate economic value on non-commensurables in the most uniform and least subjective manner possible. Non-monetary evaluation techniques attempt to quantify non-commensurables but not in dollar values. These methods attempt to measure aesthetics or to illustrate the relative effects of alternative projects on various social/aesthetic/environmental characteristics through the use of "impact" matrices.

The future options approach recognizes that society has broad multiple objectives that go beyond the objectives of water resource projects and that a complete trade-off analysis of all objectives is not possible. This approach attempts to develop contrasting sets of future options for comparisons to add useful dimensions to the evaluation process.

TABLE 2 SCORING MATRIX

FLOODPLAIN MANAGEMENT ALTERNATIVES — SCORING MATRIX		COST TO FLOODPLAIN USER (RATED DIRECT HIGH SCORE TO INDIRECT LOW SCORE)	IMPLEMENTATION AND INFORMATION REQUIREMENTS		OBJECTIVES RELATED TO FLOOD LOSSES				SOCIAL, ECONOMIC, POLITICAL WELL-BEING		ENVIRONMENTAL IMPACT	FLEXIBILITY FOR INTEGRATION WITH OTHER MEASURES	TOTAL SCORE	RANK
			RELATIVE COMPLEXITY OF INSTITUTIONAL IMPLEMENTATION	DATA REQUIREMENTS	REDUCES PRESENT LOSSES	PREVENTS FUTURE LOSSES	PREVENTS FRAUD AND VICTIMIZATION	REDUCES RISKS (SAFETY AND ECONOMIC)	PROMOTES THE ORDERLY AND EFFICIENT DEVELOPMENT OF WATER AND LAND USE RESOURCES	MINIMIZES PUBLIC HEALTH DANGER FROM MALFUNCTIONING WATER SUPPLY & WASTE DISPOSAL SYSTEMS				
CATEGORY	MEASURE / WEIGHT	3	2	2	3	3	1	3	3	2	2	2		
MEASURES TO MODIFY THE FLOOD	STRUCTURAL FLOOD CONTROL	1 / 3	3 / 6	2 / 4	3 / 9	2 / 6	0 / 0	2 / 6	2 / 6	1 / 2	1 / 2	2 / 4	48	3
	WATERSHED TREATMENT	2 / 6	2 / 4	1 / 2	1 / 3	2 / 6	0 / 0	1 / 3	2 / 6	1 / 2	2 / 4	2 / 4	40	5
	METEOROLOGICAL MODIFICATION	0 / 0	1 / 2	0 / 0	0 / 0	1 / 3	0 / 0	1 / 3	1 / 3	1 / 2	1 / 2	1 / 2	17	10
MEASURES TO MODIFY THE DAMAGE SUSCEPTIBILITY	FLOODPROOFING	3 / 9	2 / 4	1 / 2	3 / 9	3 / 9	1 / 1	2 / 6	2 / 6	2 / 4	1 / 2	3 / 6	58	1
	FLOOD PLAIN REGULATIONS	1 / 3	1 / 2	1 / 2	0 / 0	3 / 9	3 / 3	2 / 6	3 / 9	3 / 6	3 / 6	3 / 6	52	2
	URBAN RENEWAL AND RELOCATION	1 / 3	1 / 2	2 / 4	1 / 3	2 / 6	0 / 0	2 / 6	2 / 6	2 / 4	2 / 4	2 / 4	42	4
	FORECASTING WARNING AND EMERG. MEAS.	1 / 3	2 / 4	1 / 2	2 / 6	2 / 6	0 / 0	2 / 6	1 / 3	1 / 2	0 / 0	2 / 4	36	6
MEASURES TO MODIFY THE LOSS BURDEN	FLOOD INSURANCE	2 / 6	1 / 2	1 / 2	0 / 0	0 / 0	1 / 1	3 / 9	1 / 3	0 / 0	0 / 0	2 / 4	27	8
	RELIEF/REHABILITATION	1 / 3	2 / 4	2 / 4	0 / 0	0 / 0	0 / 0	1 / 3	0 / 0	0 / 0	0 / 0	2 / 4	18	9
	TAX WRITE-OFFS	1 / 3	1 / 2	2 / 4	0 / 0	0 / 0	0 / 0	1 / 3	0 / 0	0 / 0	0 / 0	2 / 4	16	11
	PROTECTION FROM LOOTING	2 / 6	3 / 6	3 / 6	1 / 3	1 / 3	1 / 1	0 / 3	0 / 0	0 / 0	0 / 0	3 / 6	34	7

The selection of procedures to evaluate alternative water resources management plans is one of the most difficult tasks facing the designer. Virtually all studies will differ in their scope, objectives, and size; therefore, evaluation procedures should be expected to differ. Some factors to be considered in the selection of evaluation procedures are the following: study objectives, plan flexibility, satisfaction of approach, allocation and distribution effects, and framework of plan. In the case of evaluating flood plain management alternatives in Southern Ontario, it is clear that economic damages are significant and that objectives other than damage aversion are present.

Therefore, the current economic assessment of water resource projects should be expanded to include non-commensurate evaluation procedures.

It is suggested that the evaluation procedure should incorporate a traditional economic benefit-cost study of direct and indirect damages with an impact matrix approach for a trade-off analysis of other non-commensurable objectives such as aesthetics, recreation, open space, uncertainty, and loss of life.

An example on the use of scoring matrix is shown on Table 2.

7.2 Comparison of Alternative Flood Control Measures - Demonstration Model

7.2.1 General

The complex issue of flood protection requires the analysis of numerous alternatives. Because the selection of the

various measures depend on the cost effectiveness and social and environmental consequences, considerable attention has been given to developing procedures for comparing the different measures. Computer models may provide a capability to look at more comprehensive sets of questions then their hand computation counterparts. As well, they can easily examine the sensitivity of any proposed solutions even where data is limited.

Computers can be used for three different types of calculations:

1. Hydrologic
2. Hydraulic
3. Damage and Economic Calculations

In Ontario, computer applications have been used mainly as labour saving tools in the application of traditional methods for hydrologic and hydraulic flood line determination. It is only recently that more sophisticated hydrologic simulations have been considered and systematic studies including damage estimates have been carried out as part of the evaluation of flood control projects.

After screening a large number of studies which compare flood management alternatives, eight assessment models described in the technical literature were given very careful screening. It was found that:

- No unique flood plain management policy alternative was consistently found to be the best for different locations.

Rather, the optimum flood control policy is determined by the flood plain characteristics and will involve a mixture of flood plain measures. As noted by James[1] where both agricultural and urban damages are small, the optimum economic policy is to suffer whatever damages occur; impending scattered urban development favours land use regulations, but development pressure may finally point to structural protection measures as the optimum.

Consideration of location restrictions as a means of delaying premature construction of structural measures and a desire to avoid intangible damages may alter the economically optimum protection level and combination of flood plain management alternatives.

Three of the models developed by the United States Corps of Engineers, James, and the United States Soil Conservation Service have the greatest merit with regard to Ontario, although others could also potentially be applied. However, adjustment of the existing models for future Ontario flood control studies in different watersheds would require several man months of effort and the complete organization and testing of such a comprehensive model could require one to two years. The necessary adjustments would require the identification of coefficients or variables that would reflect Ontario conditions and the assurance that all relevant Ontario policy alternatives were correctly reflected in the model. Studies for the implementation of such an advanced methodology is strongly recommended for future work in flood control in this province.

1 *L. Douglas James "Economic Analysis of Alternative Flood Control Measures", Water Resources Research Volume 3, Number 2, 1967.*

7.2.2 Model Selected

For this study in order to demonstrate the effects of flood plain management alternatives, a single event watershed model HYMO and a simplified economic damage model were assembled. The watershed model, an existing hydrologic computer model developed by the United States Department of Agriculture, computed flood hydrographs from various sub-basins of a watershed and routed the floods through the streams and valleys of the watershed. The program is well written and easily modified. The economic sub-routine was added in order to obtain flood damages at selected points throughout the watershed. For these points, the model will compute for a selected flood; the depth, duration and the direct damage caused by the flooding.

The direct flood damages were calculated using updated stage-damage curves derived by H. G. Acres Limited in their submission to the joint task force on Water Conservation Projects in Southern Ontario (1968).

Two watersheds were selected to model a variety of physical conditions found in Southern Ontario. Watershed A was assumed to be oblong shaped having a drainage area of 80 square miles with the typical steep slopes and valley flood plain characteristic of the watersheds draining into Lake Ontario.

Watershed B draining a fan shaped area of 29 square miles had a flat river gradient, a small river channel and a large flat flood plain, characteristics typical of watersheds found in Southerwestern and Northeastern Ontario. Where possible, the watersheds were selected where there was sufficient stream flow records to authenticate the derived stage - frequency and damage-frequency curves.

During the calibration process comparisons were made between historic and simulated floods with regard to quantity and frequency of occurrence. Subsequently flows were generated for each watershed for Hurricane Hazel and the 100 year, the 50 year and the 10 year storms.

Four flood damage sites were selected on Watershed A. Drainage areas for the sites varied from 7 square miles to 79 square miles. Two flood plain land use mixtures were selected based upon the input of the Land Use Study. The first flood plain land use mixture used the average flood plain land uses obtained from a survey of 19 Ontario urban municipalities. The average land use consisted of approximately 14% residential, 3% commercial, 8% industrial, 5% institutional, and 70% open space, agricultural.

The second flood plain land use mixture described the land use of Windsor which with its 46% residential land use represented the largest development of the flood plain. The area was assumed residentially developed at a density of 5 units per acre containing mass produced (non-luxury) detailed houses with basements.

Results of the foregoing demonstration models are discussed in Section 8.1.1 with respect to levels of protection and resultant damages.

8. ASSESSMENT OF ALTERNATIVES

8.1 Design Floods

Calculation of design floods could be based on any of the following three types of floods:

(a) synthetic
(b) highest observed
(c) selected frequency

The present design floods; Hazel and Timmins are based on (b), while the 100 year flood in Eastern Ontario and parts of Northern Ontario are based on (c).

Synthetic Floods

A change of design floods to a more severe event than the current criteria could be based on a combination of hypothetical snowmelt/rainfall and runoff conditions. This may be an observed storm such as Hurricane Agnes which did not occur in Ontario but which could be considered reasonably characteristic of the region. The 18 inch rainfall from this event in Pennsylvania over a 5 day period, was almost twice the Hurricane Hazel rainfall values used for the Ontario criteria.

On the other hand, the maximum probable flood based upon the consideration of all factors that would produce the heaviest rainfall and maximum runoff may be adopted. Such rare floods are used currently in Ontario for spillway designs, especially when the structure is located upstream of an urbanized area. Recent dam disasters in the United States and other countries have demonstrated the implications of adopting a lower design standard.

The adoption of such a severe storm criteria for the calculation of design floods and regulatory floodlines would increase the amount of land to be reserved for flood plain and could reduce future flood damages.

<u>Highest Observed Flood</u>

Hurricane Hazel and the Timmins storm are presently considered to be the rainfall events responsible for the highest observed floods in the Province. Accordingly, they have been adopted as Regional Storms for the calculation of floods and regulatory floodlines. While their recent occurrence permits residents to invisage resultant flood damages, the problems in determining their frequency and applicable areas of occurrence continue to invite criticism. Nevertheless, floodlines produced by these storms represent the useful planning information especially in reviewing proposed flood plain developments which could endanger human life.

In order to avoid some of the present confusion, the three hydrologic areas currently used for design criteria, namely Hazel, Timmins and 100 year flood, could be described as three separate zones. Zone 1 would be similar to the existing Hazel area; Zone 2 would include Eastern Ontario which is currently using the 1 in 100 year flood; and Zone 3 would include the Timmins flood area. For Northern Ontario watersheds past experience showed that two studies have to be carried out; Timmins and the 100 year flood, to see which one provides more severe conditions. Generally, large drainage areas, with 1,000 square miles or more, exhibit larger peak flows from the 1 in 100 year flood than the Timmins flood. For each zone a separate manual should be prepared listing the necessary design parameters.

A map of Ontario identifying the three zones is shown on Figure 3.

The current methods of calculating runoff produced by the two highest observed storms tend to result in inflated peak values. This is mainly due to the antecedent factors and the watershed response times used in flood plain studies. Recent analyses of recorded flow data in the Windsor and North Bay areas demonstrated that the estimated flood peaks generated by the Hazel and Timmins storms could be reduced if local recorded stream data is used for the calibration of the Soil Conservation Service unit hydrograph method, rather than the general parameters developed in the United States.

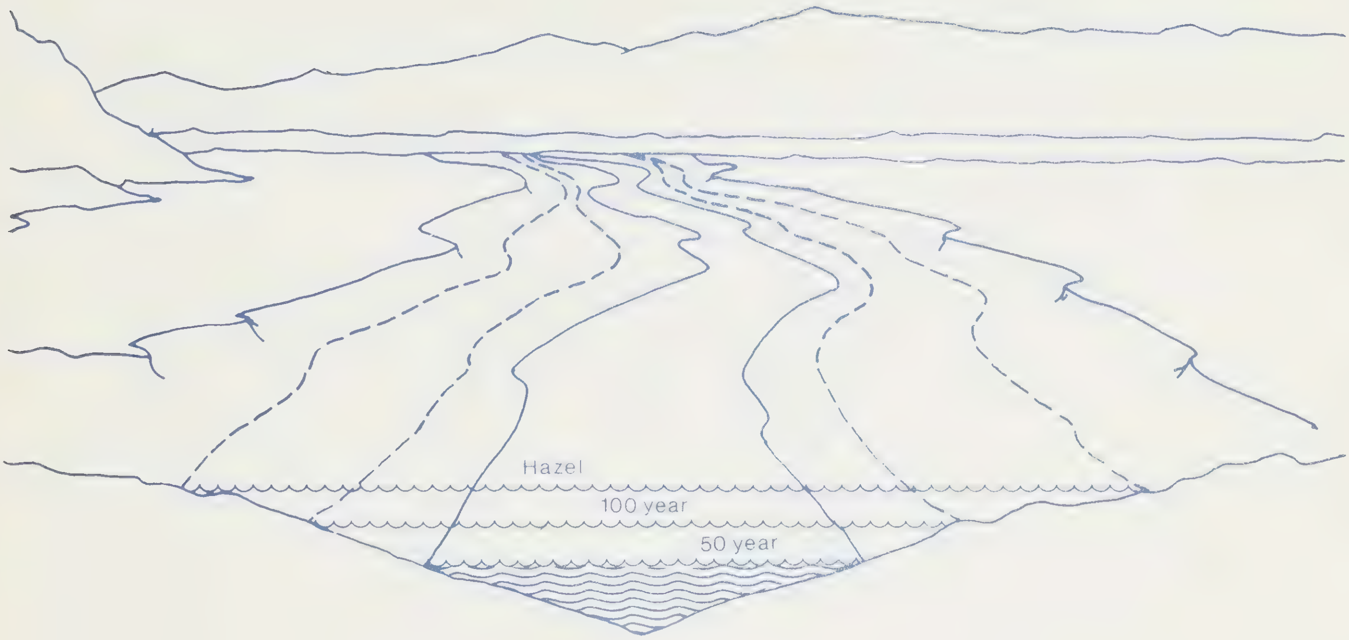
Regardless of the method used to predict flood flows, hydrologic parameters represeting Ontario conditions are essential to refine the estimates of design floods, hence flood plain limits.

Selected Flood Frequency

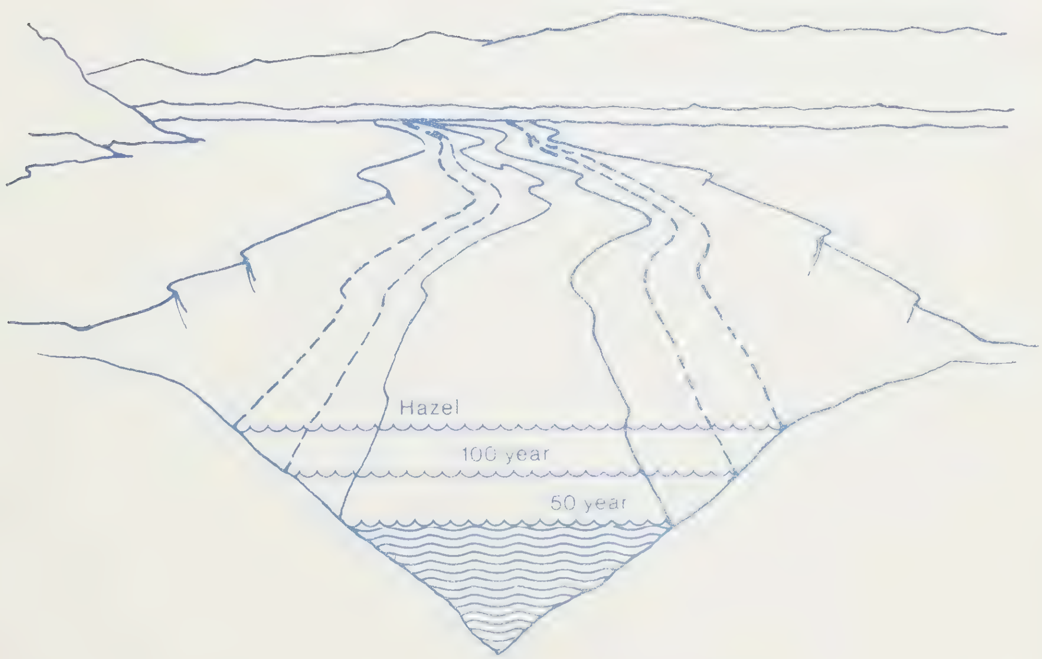
The use of flood frequency in the definition of design criteria would permit the introduction of a risk factor. In this manner an individual seeking to locate in a designated flood hazard area could estimate the chance of flood damages to be experienced over the amortization period of his investment. The time horizon for the investment must be carefully considered in light of community interests. In the example of buildings sold within a short period after construction, the perceived flood hazard by the original owner is minimal.

The selection of one flood frequency for purposes of flood plain management throughout the Province would permit a more

SKETCH SHOWING 50, 100 YEAR AND HAZEL FLOOD PLAINS



Shallow - Wide Flood Plain



Narrow - Steep Flood Plain

Figure 4

equitable basis for regulatory policies. At present, the difficulty in assigning probabilities of occurrence to the Regional Storms suggests that the criteria now applied within the three hydrologic zones shown in Figure 3 may not be similar. For this reason, the extent of flood plain lands subjected to regulatory policies may vary from one zone to another.

A review of the uncertainties involved with the present state of the art of hydrologic investigations and the accuracy of topographic mapping, indicates that the use of the 1 in 100 year flood should be considered as a minimum criterion.

Further, past flood plain management experience reveals that whenever urban areas are involved, the tendency has been to increase the protection level to 100 years and much higher for design purposes. There has come to be a fairly general acceptance of the 100 year floodline as a reasonable limit between site occupancy and excessive exposure to flooding. This is supported by the fact that the 1 in 100 year flood is accepted by the Federal Government and most foreign countries as the minimum criterion.

8.1.1. Protection Level

When a flood frequency criteria is established as a basis for flood plain management, it is generally acknowledged that larger floods could and do occur. However, citizens knowingly assume that by meeting the requirements of flood plain regulations, they have therefore protected themselves completely against future floods. This problem is compounded by today's mobile population that moves into areas, completely

unaware of any hazards. The use of an unwarrented small flood for regulatory purposes may result in decisions on the use of flood lands that could be particularly hazardous to life and health.

As the required flood protection level is lowered, the likelihood of a damaging flood is increased proportionally; the chances are about twice as great that a 50 year flood will occur in a given year than that of a 100 year flood. Not only is there a greater likelihood that the property will be subjected to flood damage during its useful life but when floods do occur damages to the property will be greater because of increased flood depths and velocities. This is especially true in steep narrow flood plains, illustrated in Figure 4, which gives rise to turbulent high velocity flows that may sweep away homes located in the central flood plain. In addition rescue and relief measures will become increasingly difficult.

In addressing the problem of an optimum protection level, the drainage area must be considered in relation to the benefits provided by a flood control project. In the upland position of watersheds, the provision of adequate drainage is normally regarded as a municipal responsibility but these schemes are generally directed to reducing inconvenience and alleviating health hazards through the efficient removal of frequent runoff events. The prevention of flood damage is mainly considered to be a secondary objective. It is therefore apparent that the urban drainage system has two components related to objectives and associated benefits; the foregoing "minor" system which provides for the drainage of frequent runoff events, and a "major" system which accommodates the rarer, more severe events.

TABLE 3: EFFECT OF URBANIZATION ON A 125 SQUARE MILE WATERSHED

Return Period	PEAK DISCHARGE IN C.F.S.			
	No Development	25% Urban	65% Urban	100% Urban
5 Year	2770	2780	7300	9150
10 Year	3600	3680	9100	11500
25 Year	4670	5150	11800	15000
50 Year	5450	6500	14100	17000
100 Year	6200	8150	16800	21300
500 Year	7900	13300	24300	30600

Reference (83)

The currently ongoing provincial-federal drainage study reportedly will provide the necessary guidelines to delineate these systems. Should these recommendations be acceptable to the various ministries, they could be adopted as municipal standards thereby eliminating the one-half square mile drainage area which now defines municipal responsibility.

Urbanization has been identified as a major factor influencing floods since the peak discharge will increase substantially as development occurs. This is illustrated in Table 3 which shows that a rare flood experienced in the past under predominantly rural conditions may reoccur with increasing frequency under urban conditions. The demonstration model also confirmed a growing awareness that small watersheds are affected more dramatically. It is therefore evident that flood plain management must be cognizant of proposed watershed development to ensure that programmes will continue to maintain levels of protection which were originally envisaged. In addition, the significance of land use changes upon streamflows cannot be considered solely in terms of design flood peaks but should be analyzed from an environmental viewpoint.

A review of existing flood plain maps completed for conservation authorities together with results of the demonstration model illustrated flood conditions which may be experienced for various design frequencies.

Flood Conditions Related to the 100 Year Value

Design Criterion	Flood Peak	Flood Level	Flood Plain Area
Hazel or Timmins	125%-200%	1'-4' above	140%-200%
100 Year Flood	100%	DATUM	100%
50 Year Flood	75%- 85%	0.5-2' below	70%- 90%
25 Year Flood	65%- 75%	1'- 3' below	50%- 80%

TABLE 4

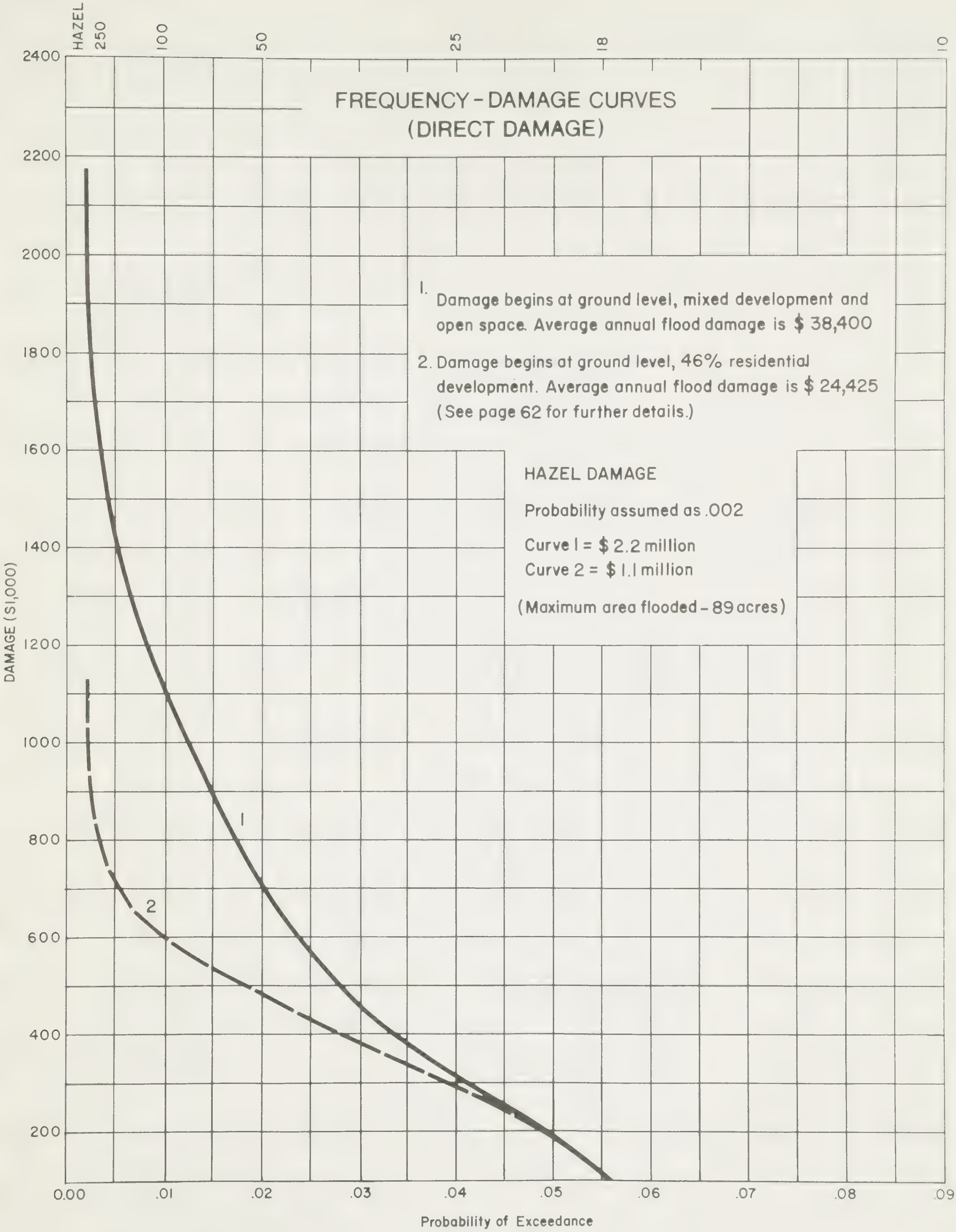
SUMMARY OF FLOW CONDITIONS

TEST WATERSHED #A

Location	Total U/S	10 Year		25 Year		50 Year		100 Year		Hazel	
	Area (s.m.)	Elev.	Q (cfs)	Elev.	Q (cfs)	Elev.	Q (cfs)	Elev.	Q (cfs)	Elev.	Q (cfs)
Urban Area # 1	24.2	700.4	2,570	701.2	3,390	701.6	3,860	702.0	4,460	703.0	6,520
Urban Area # 2	6.8	660.7	2,080	660.9	2,600	661.0	2,710	661.0	2,820	661.2	3,400
Urban Area # 3	65.0	377.4	5,310	378.1	7,060	378.4	8,190	378.7	9,490	379.8	14,550
Urban Area # 4	79.7	256.5	4,490	257.1	5,920	257.3	6,930	257.7	8,130	258.6	12,270

Q = peak flow in cubic feet per second -Area in square miles -Elevation in feet above Geodetic Datum

Test Watershed #A is an oblong-shaped watershed typical of the steeply sloping watersheds draining into Lake Ontario. In the lower portion of the Watershed (Urban Area 3 and 4) the stream is characterized by steep valley banks forming a well defined valley flood plain. In the upper portion of the watershed the stream channel is small and there is no clearly defined flood plain (Urban Area 2). The watershed is covered with a till plain and over 50% of the watershed is urbanized.



HAZEL
250
100
50
25
18
10
FREQUENCY - DAMAGE CURVES
(DIRECT DAMAGE)
1. Damage begins at ground level, mixed development and open space. Average annual flood damage is $ 38,400
2. Damage begins at ground level, 46% residential development. Average annual flood damage is $ 24,425
(See page 62 for further details.)
HAZEL DAMAGE
Probability assumed as .002
Curve 1 = $ 2.2 million
Curve 2 = $ 1.1 million
(Maximum area flooded - 89 acres)
DAMAGE ($1,000)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
1
2
0.00
.01
.02
.03
.04
.05
.06
.07
.08
.09
Probability of Exceedance

Figure 5

The actual flood severity, commonly measured in terms of water depth, area inundated and water velocity is location dependent. In addition to upper watershed characteristics, the channel capacity and the extent of level land adjacent to the channel are important underlying factors. However, as indicated in Table 4, flood severity is not directly proportional to flood frequency. A large increment in precipitation will usually result in a moderate increment in flows but for large floods, this will generally result in an insignificant increase in flood stages.

Damages due to flooding depend on the flood severity at a site and the nature and manner of land use. Some general classes of land use are more susceptible to flood damage than others. The demonstration model developed for the study was used to evaluate the damages in the typical watersheds outlined in Section 7.2.2 for various development patterns and flood plain policies.

For example, the estimated damages for a flood plain developed outside the 10 year flood line are shown on Figure 5 for two land uses: the average flood plain land use obtained from 19 Ontario urban municipalities, and the highest residential development (46%) as found in the City of Windsor. The values for the former land use pattern, tabulated in the following table, highlight the increased damages that are incurred for progressively severe flood events. It is also apparent from Figure 5 that flood damages will increase with the intensity of economic activity on the flood plain.

Total Damages in Million Dollars for Mixed
Development Due to the Design Flood

Design Criteria	Direct	Indirect	Total
Hazel	$2.2	.6	2.8
100 year	1.1	.3	1.4
50 year	.7	.2	.9
25 year	.3	.1	.4

To provide an insight into the effect that regulatory levels have upon flood damages, average annual damages were evaluated for four scenarios represented by development outside the 25, 50, 100 and 250 year flood lines. The average annual damages represents the average loss per year due to flooding and equals the total damages inflicted by all floods weighted by their probability of occurrence. Results show that the average annual flood damage for a 25 year regulatory level is approximately 3 times greater than the flood damage for a 100 year regulatory level and approximately 7 times greater than a 250 year regulatory level.

In essence the matter resolves into what is considered a desired allocation of costs when flood damages occur and what is a reasonable protection level for life and health. As the flood protection level is lowered, this will result in a greater subsidy to the flood plain occupant through the various flood related programs. The question arises as to whether assistance should be given only to those persons who suffer catastrophic losses from rare flood events or should assistance be given to those persons who suffer losses from floods which occur on a regular basis and against which the person would likely have avoided losses through prior action.

8.2 Alternative Protection Methods

Watersheds undergoing development require investigation of flood control alternatives to be used for flood plain management. Alternatives to be considered for flood damage reduction include various structural corrective methods such as dams, channel improvement, dyking, flood-proofing, or preventive flood plain regulations. A shift in recent times to planning and implementation of non-structural alternatives from the conventional structural solutions is widespread in North America and elsewhere. The past reliance in many countries solely upon flood control works indicates that the vulnerability to catastrophic losses will increase. That is, a larger portion of the total flood losses will come from very extreme events which overtop levees or reach areas which have not been inundated within recent memory. Frequently this occurs at the expense of new development which has been lured onto the flood plain with a false sense of security.

While the corrective methods are not always feasible or require large capital investments, the preventive flood plain regulations are sometimes contrary to the existing development plans advocated by the municipalities.

Experience has shown that no single management alternative is free of disadvantages. The merits of each must be considered on a case by case basis. The management techniques presented in Table 5 have generally been available to the water resource manager for many years; however, one relatively new regulatory approach has shown considerable promise in accommodating a reasonable level of urban development in portions of the flood plain while minimizing the flood damage potential.

TABLE 5: ADVANTAGES AND DISADVANTAGES OF ALTERNATIVES

Alternatives	Advantages	Disadvantages
Dykes levees, floodwalls	Low initial cost provides effective barrier to development	High maintenance cost. Decreased floodplain. Higher floods create excessive damage. Space requirement in urban areas.
Dams, Reservoirs	Could be multi-purpose project	Floods in excess of design could create problems downstream. Environmental constraints fish, wildlife, sediment, water temperatures. Requires careful operational procedures.
Channel Improvements. Stream diversions	Minimum land requirement, reduces levels for floods greater than design floods, localized effects.	Possible increase in downstream flows. Expensive utility relocations. Safety of children. Higher velocities. Increased erosion.
Watershed Treatment		Not very effective. Only long term effects. Difficult to estimate and plan.
Floodplain Regulations	Can be used with other structural alternatives. Single district or two district approach can provide flexibility if required.	Not effective for existing development in the floodplain. Requires accurate mapping and flood data.
Flood proofing	Can be used with other alternatives.	Not applicable over 2-3 foot depth. Does not eliminate floods. Lacking adequate technology. Requires detailed regulations.
Urban Redevelopment	-	Frequently not feasible. Expensive.
Forecasting	Inexpensive.	Not effective on its own. Only on large rivers is effective. Requires extensive data base and instrumentation.
Insurance	Residents are made aware of risks. Good for transition periods between change in land use. Provides immediate assistance.	Requires the government to underwrite. Will not eliminate flooding. Requires complimentary control.

This method is called the two zone concept and is described in detail in the following chapter.

8.3 Two Zone Concept

Flood plain management standards are generally related to two objectives, 1) the needs of nature; and 2) the needs of man. The first need is accommodated by retaining the channel of the stream and as much of the flood plain adjacent to the stream as is needed to convey the design flood. This area is commonly called the floodway. Typical land uses permitted in these areas include open space, agriculture, recreation, and limited parking. Filling and structures not associated with open space use are not permitted in the flood plain.

The needs of man can be accommodated by acquiring areas of flood protection outside the floodway which could be subject to inundation. However, in times of flooding these higher areas are associated with shallow flooding depth and slower flood velocities.

Although any filling or building on the flood plain will tend to increase flood heights, if such development is limited to areas outside the natural floodway, the increases in flood heights are generally small. When filling is placed in these areas, sometimes called flood fringe areas, above the elevation of the design flood, it would permit development, as shown on Figure 6.

Because of the many factors which must be weighed in the selection of a floodway, it has been considered the most difficult part of the flood plain to define. Many different criteria have been proposed to delineate the floodway

THE TWO ZONE FLOODWAY - FLOOD FRINGE CONCEPT

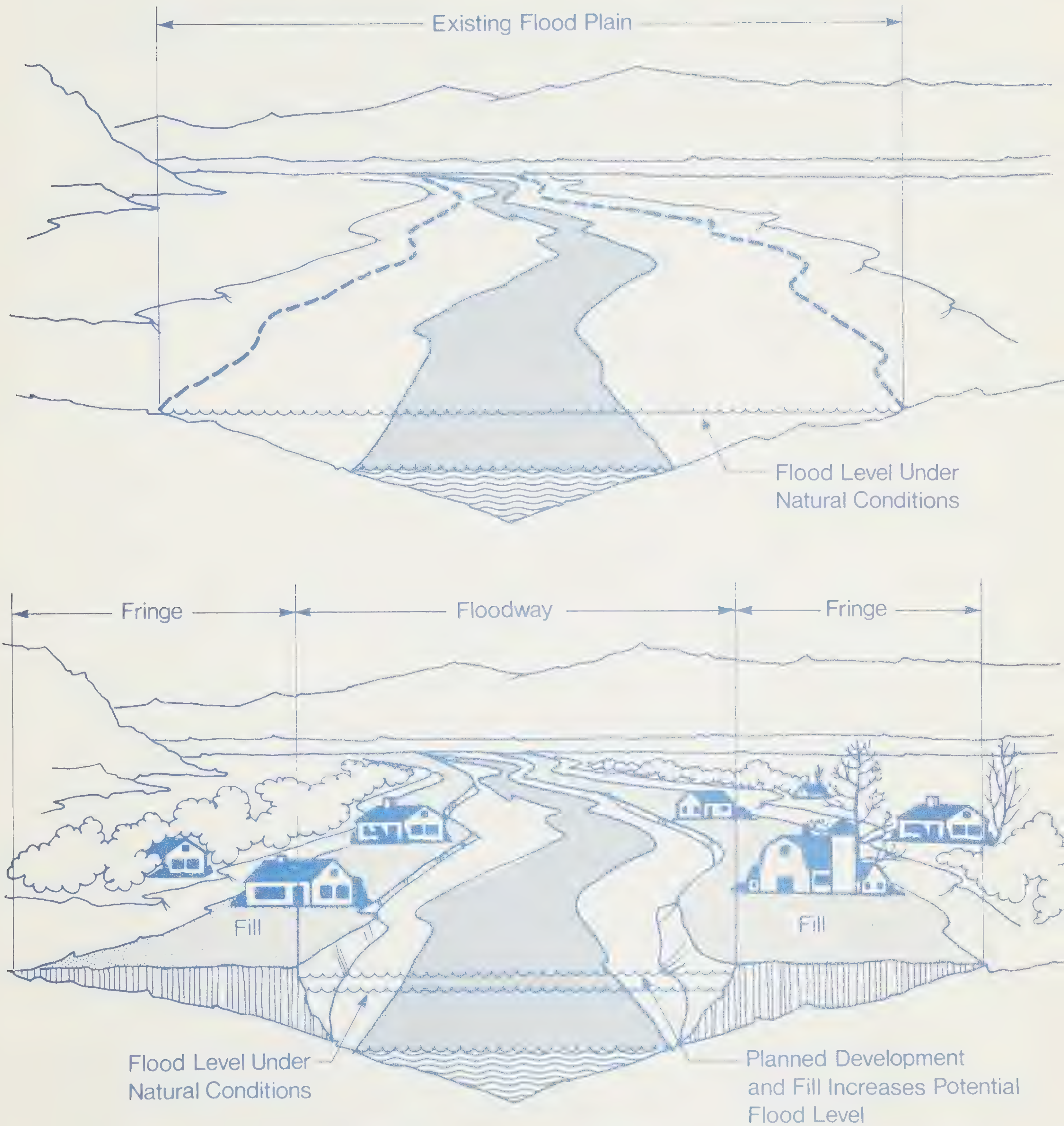


Figure 6

including water profile rise limitations, product factors of velocity and depth, limitations on velocity and depth and lesser flood frequency flood plain limits. While there is little concensus of opinion on the optimal two zone approach, for administrative purposes it is recognized that the engineering criteria should be non-complex, understandable and reproducible. The United States Corp of Engineers has advocated the water profile use approach and recently this method has been recommended by Environment Canada as part of the National Flood Damage Reduction Programme.

Following this approach, when existing development or social and political considerations dictate the use of part of a flood plain, it is necessary to determine the changes in flood heights which are attributed to the planned encroachment. Increases in flood heights resulting from filling and developing within the flood fringe areas, are usually limited to increases between 0.2 to 1 foot.

Further, the design frequency used for floodway calculations in the United States is the 1 in 100 year flood, however 1 to 2 feet of freeboard may be added as a factor of safety to determine the minimum level required for flood proofing measures.

The amount of freeboard will vary according to local conditions, but general guidelines recommend their use especially if floods considerable larger than the regulatory flood would cause much higher flood stages.

Engineering calculations for the design of a floodway are carried out in two stages. In the first phase, the water surface elevation due to the selected design storm, is calculated before any encroachment is permitted on the flood

plain. The second set of calculations assumes a limit of encroachment and a new design water surface elevation is calculated which will now be confined between the new encroachment lines. This new elevation reflects the flood stage that would be created by the same flood in the future. For purposes of hydraulic computations, it is assumed that the flood fringe area is filled solid and has no overbank storage nor floodflow capacity. The loss of valley storage by confinement of the flow to the floodway can be significant and while experience in the United States indicates that the increased discharges associated with are generally small, it should be accounted for in determining the floodway's areal requirements.

Severe floodway encroachment may give use to numerous problems in developing the flood fringe for urban use.

As floods ignore political boundaries, proper hydraulic transitions must be established between adjoining communities. Any increases in flood heights attributable to a floodway selection of one community, should have negligible effects on adjoining communities. While higher flood levels will result in more flood plain land available for development, the same levels may make flood-proofing of structures impractical or unrealistic.

Similarly, increased flood velocities near the floodway limits will create erosion problems and a potential for water pollution. The above problems can only be minimized if the initial floodway selection is based on a small increase in water surface profile. The two zone flood plain regulations like any other type of control, must be flexible to meet changing conditions and needs. Future adjustments of the floodway line consistent within the limits of applicable criteria are possible.

8.4 Implementation Policies

Although implementation of policies is outside the Terms of Reference, the following comments may serve as a useful guide. The responsibility for the implementation of the flood plain management techniques and practices will have to be met by the Province of Ontario working in conjunction with conservation authorities and municipalities. The province should establish general guidelines for flood plain management taking into account special local circumstances. All major population centres throughout the province are now included within a conservation authority. Accordingly, detailed regulations concerning the nature of flood plain development, if any, should be the responsibility of conservation authorities through their powers under the Conservation Authorities Act and municipalities through the official plans and zoning by-laws of The Planning Act.

One such policy should introduce control procedures whereby all official plans include a flood plain designation and land use policies for the flood plain. Official plans can be broken down into two categories with respect to flood plain management; undeveloped and developed areas, to reflect the differing development characteristics of municipalities throughout the province.

1) Undeveloped areas

   rural municipalities with little or no pressure for development within their flood plains;

   urbanizing municipalities which are confronted with a great deal of pressure to allow a certain measure of development within the flood plain; and

2) Developed areas
older urban municipalities with significant development on the flood plain who are in pressure for future development or redevelopment on the flood plains.

It is suggested that in the assessment of alternative policies, the above two groups should be viewed separately for these two groups.

Urbanizing municipalities are confronted with a great deal of pressure to allow a certain amount of development within the flood plain. These municipalities are probably prepared to restrict all development within a floodway, but argue that certain developments should be allowed in the flood fringe areas provided that adequate flood-proofing is incorporated into the building design.

In order to curb future flood damages in established urban municipalities, it will be necessary to adopt comprehensive flood plain management programmes involving both regulatory and corrective measures. The municipalities may favour a system by which their land use policies are based on "special studies" taking into account a wide range of economic, social and engineering factors. New analysis techniques, which are used to select possible management alternatives, should include the traditional economic benefit-cost studies, listing direct and indirect damages and an impact matrix approach for trade-off analysis.

Most flood plain studies in Ontario have considered future land use within the tributary watershed and its effect upon flood characteristics. Before commenting on a major development outside a flood plain, a designated government agency should be required to compare the proposed land use with the

assumptions made during the flood plain study. If development is more intense than originally foreseen, approval should be conditional on impacts upon regulatory floodlines and existing flood control works.

The investment in the current flood control programme throughout the Province has been substantial. Therefore, the implementation of new criteria should necessarily be carried out over a two to three year period possibly involving demonstration projects to fully acquaint flood plain managers with the revised programme. Available funding will largely dictate the scope of this effort; therefore, existing flood plain studies and mapping should be used to the fullest possible extent.

The approximate cost of past "simple" flood plain studies is $2,000 per mile. More sophisticated, and/or newly developed methods of analyses would undoubtedly cost more but this additional cost could most probably be justified especially in the case of urbanized areas.

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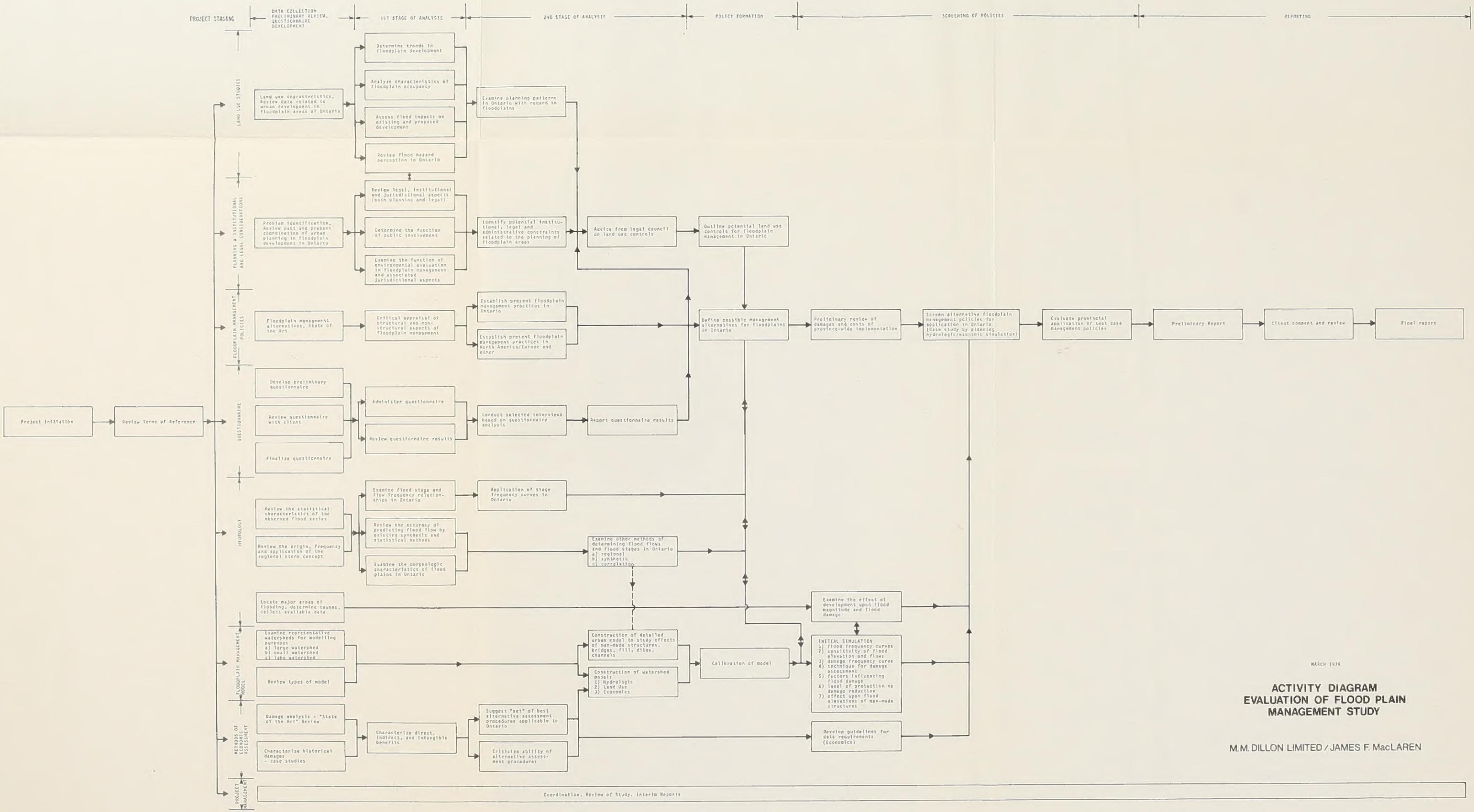
GLOSSARY

Channel Capacity	The maximum flow which is contained within the river banks and does not overflow the adjacent low lands.
Dam	A structure in and across a river valley to impound, control and otherwise regulate the river flow.
Design Flow	A certain magnitude of flow which is used for designing corrective or preventive measures along the water-course.
Drainage Area	The land surface which contributes runoff.
Fill Line	A line delineating limits within which no fill can take place without permission from the local conservation authority.
Flood	An overflow or inundation coming from a river or other body of water.
Flood Control	The prevention of flooding by controlling the high water stages by means of storage reservoirs, dykes, diversions or channel improvements.
Flood Hydrograph	A hydrograph which covers only the flood period.

Flood Line	Line delineating the extent of flooding due to a specific flood event.
Flood Plain	The land adjacent to the river which will likely be inundated in the event of a flood.
Floodway	The channel of a river or stream and those portions of the flood plains adjoining the channel, which are required to carry and discharge the flood water.
Freeboard	The vertical distance between the maximum permissible level and the top of the dam or dykes.
Hazard Line	Line which delineates an area where development could be hazardous to man or to the environment.
Hydraulics	As applied to conservation deals with the measurement and control of runoff from river drainage basins.
Hydrograph	A plot of flow against time and is a correct expression of the detailed runoff of a stream resulting from all the varying physical conditions which have occurred on the drainage area above the gauging station previous to the time which it represents.

Low Flow Augmentation	This phrase describes the water released from a reservoir to increase the flow of a stream for sewage dilution, riparian rights and other purposes.
Multi Purpose Dam	A dam that is used for many purposes such as flood control, low flow augmentation, recreation etc.
Precipitation	Includes rain and snow.
Regional Storm	A storm which is used for flood line calculations for a particular region of Ontario.
Reservoir	The body of water created by the construction of a dam.
Runoff	That portion of precipitation that is transmitted through natural surface channels. In general, it is defined as a portion of precipitation which is not absorbed but finds its way into the streams.
Spillway	That part of a dam over which the excess water is discharged.
Storm	A meteorological disturbance which is either unusual or of great magnitude, rate or intensity.

Stream Gauge	A measuring device used to determine the elevation of water at selected points.
Watershed	Drainage area, drainage basin or catchment area.



MARCH 1976

ACTIVITY DIAGRAM
EVALUATION OF FLOOD PLAIN MANAGEMENT STUDY

M.M. DILLON LIMITED / JAMES F. MacLAREN